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August 31, 1964

THE EFFECT OF NUCLEAR RADIATION ON ELASTOMERIC AND PLASTIC COMPONENTS AND MATERIALS

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Addendum Report on

THE EFFECT OF NUCLEAR RADIATION ON ELASTOMERIC AND PLASTIC COMPONENTS AND MATERIALS

by

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to

RESEARCH TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND

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ABSTRACT

This report is an addendum to REIC Report No. 21 and presents the state of the art of the effects of nuclear radiation on elastomeric and plastic components and materials from 1961 to the present.

The mechanism of radiation damage and the effects of radiation in various environments are briefly discussed. Data summarizing the radiation-effects information on specific components and on the various types of elastomers and plastics are presented in detail. Areas in which additional work is needed are indicated. Radiation polymerization or vulcanization are not covered in this report.

The report is intended to be sufficiently inclusive to make it valuable as a reference guide relative to radiation effects under varying conditions of temperature and vacuum on elastomeric and plastic components and materials.

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THE EFFECT OF NUCLEAR RADIATION ON ELASTOMERIC AND PLASTIC COMPONENTS AND MATERIALS (ADDENDUM REPORT)

SUMMARY AND CONCLUSIONS

There is a widespread interest in polymeric materials which may be used in aerospace applications. There is an increasing demand for information on the behavior of these materials in a radiation environment (nuclear, ultraviolet and particle radiation), in a high vacuum, and at extreme temperatures. This is reflected in the amount and types of publications which have become available since the publication of REIC Report No. 21 on "The Effect of Nuclear Radiation on Elastomeric and Plastic Components and Materials". The amount of data which has become available since 1961 is somewhat limited, although both the quality and scope have improved. The trend, noted in Report No. 21, of testing components in the environments to be encountered in actual operation has increased. Data on the behavior of polymers in a radiation-vacuum -extreme temperature environment have become available. Because of the difficulties in obtaining data of this type, the amount is still limited. However, it is encouraging to see the progress in this direction.

In general, materials having a high degree of cure, high molecular weight, good heat resistance, and little or no plasticizer or other volatile additive show promise for use in [illegible] environment. In some cases, the radiation resistance of a material is improved in vacuum because of the lack of oxygen which is generally the major contributing factor to polymer deterioration.

Polyimides and phosphonitrillic chloride polymers have been reported as having improved radiation stability over presently used polymers and merit consideration for further development and application in end items. O-rings manufactured from rubber compositions containing antirads have shown improved service life in a radiation environment, although this improvement still falls short of the requirements for many applications. Several structural adhesives and laminates have been found to be satisfactory in radiation exposures at cryogenic temperatures. These include polyurethane, epoxy and modified epoxy, phenolic, and polyester materials.

In this addendum report, a brief summary of the effects of radiation and other known environmental conditions is given for end items and materials. A comparison of the relative resistance is provided by Figures 1 through 4 and Tables 1 and 2, which show the stability of the various elastomers and plastics to gamma radiation as well as noting the general effects of vacuum and ultraviolet radiation on these materials. At the present time, data are not sufficient to definitely establish the life of a particular material for all conditions of exposure, but the data do give guidelines which will help to determine the proper use of various types of polymeric materials.

In general, the vacuum environment has not proven to be too severe. Most of the polymeric materials have not been too seriously affected by this environment and have maintained satisfactory properties. Several plastic materials have shown promise for use at cryogenic temperatures. In most cases, the effects of nuclear radiation under

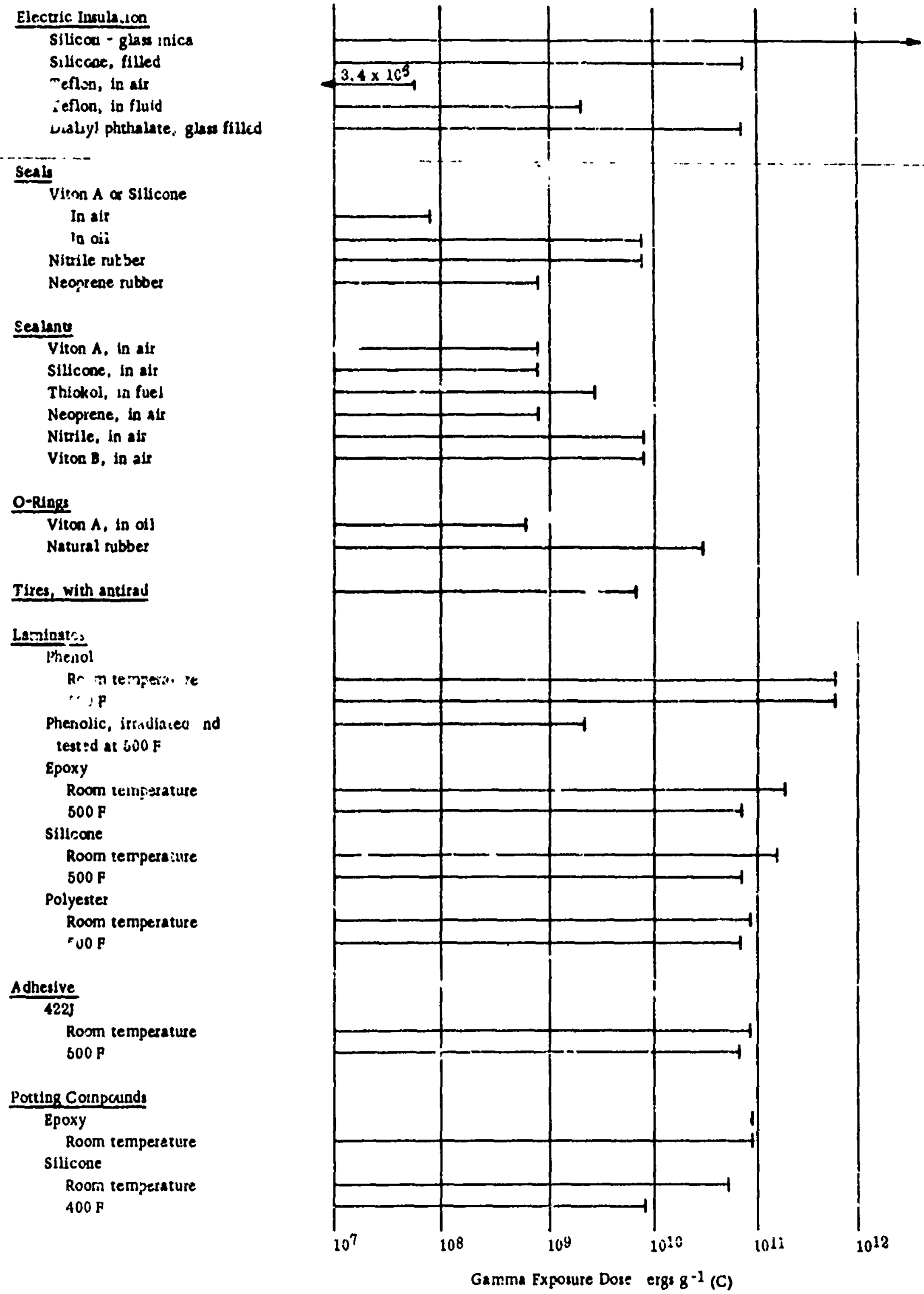

FIGURE 1. MAXIMUM RADIATION EXPOSURE OF VARIOUS COMPONENTS FOR RETENTION OF USEFUL PROPERTIES

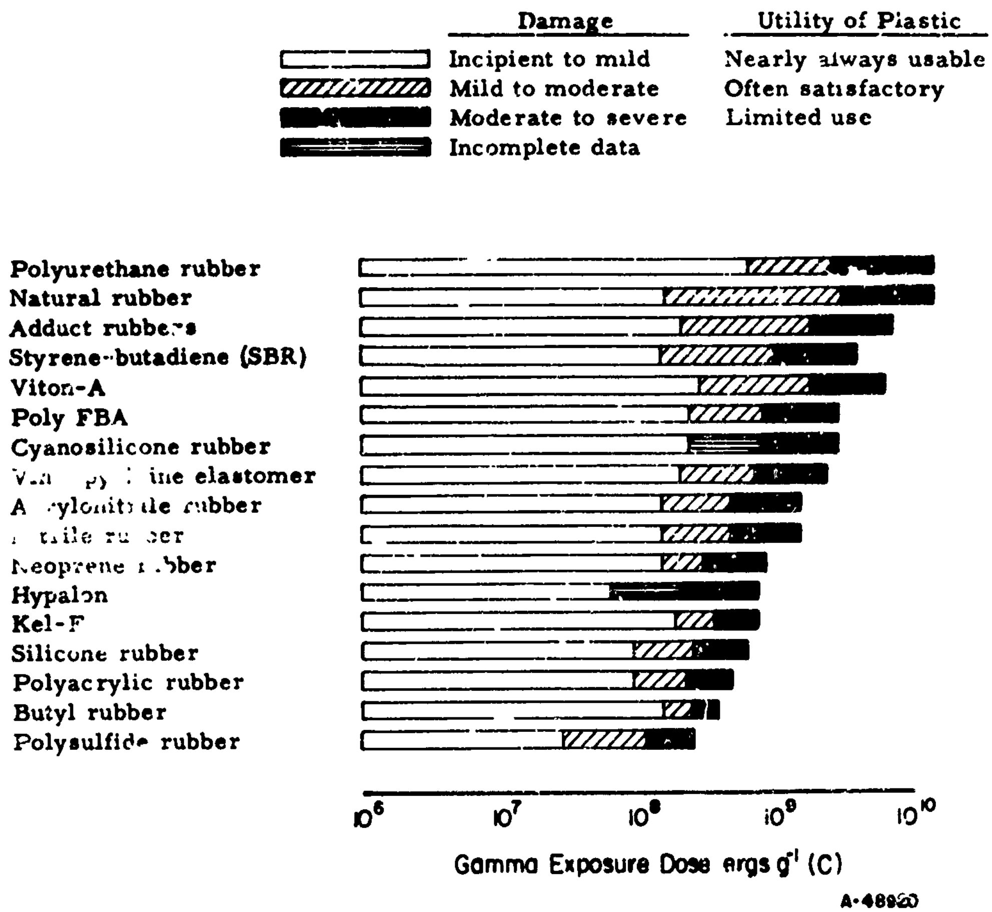

FIGURE 2. RELATIVE RADIATION STABILITY OF ELASTOMERS

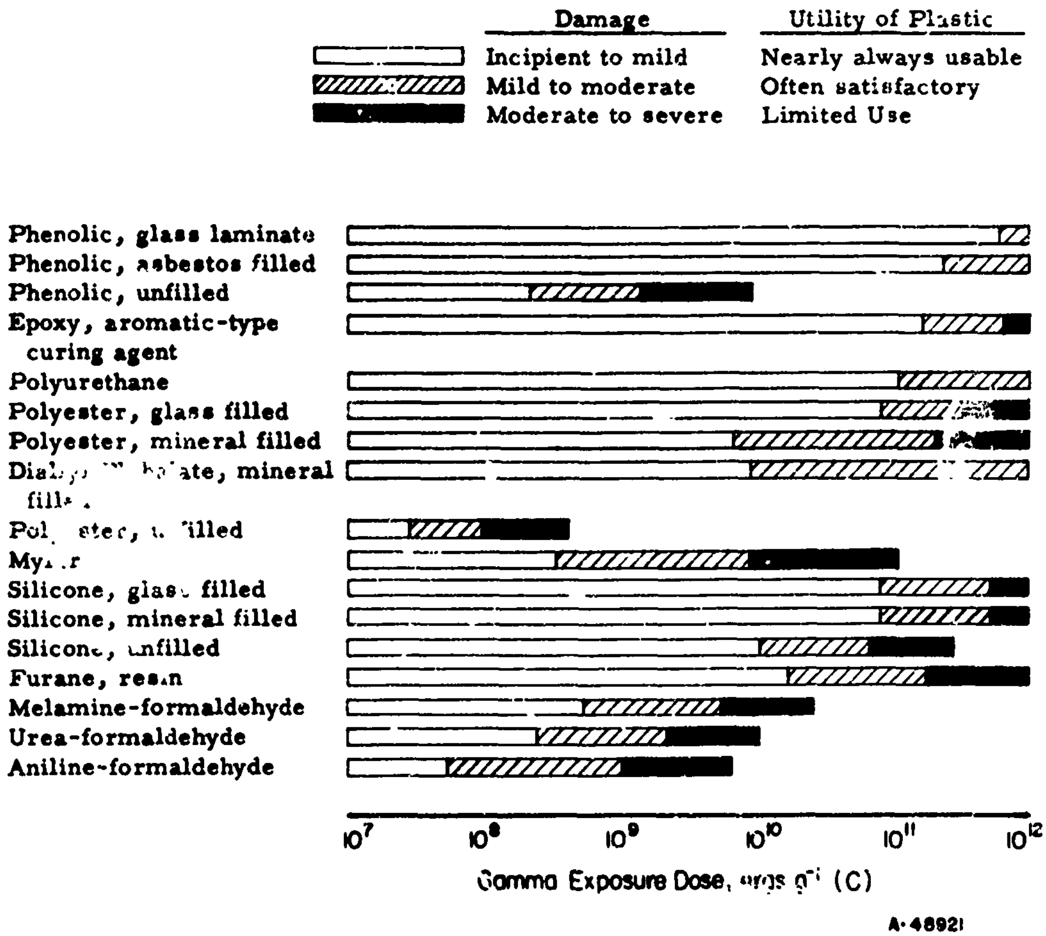

FIGURE 3. RELATIVE RADIATION STABILITY OF THERMOSETTING RESINS

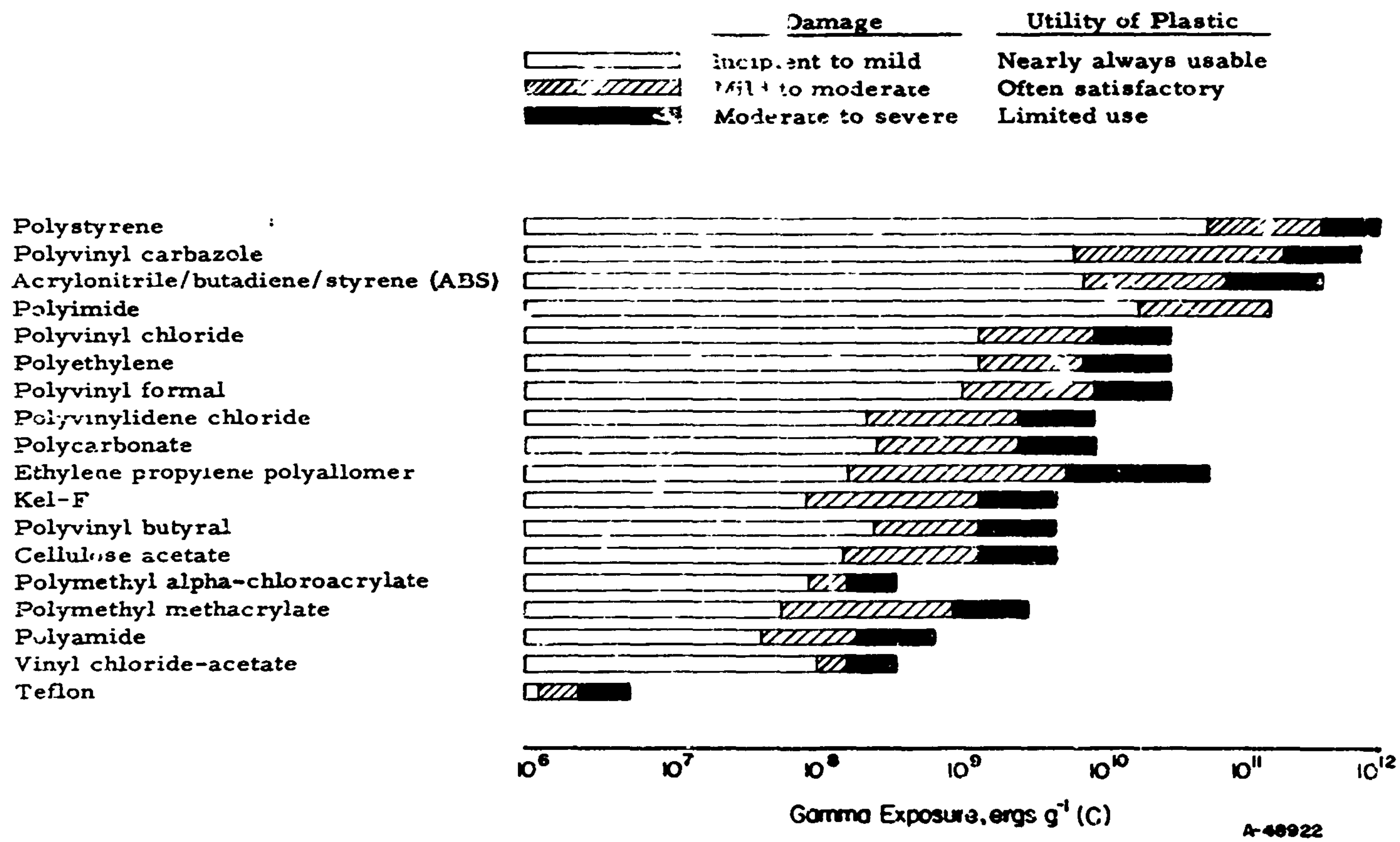

FIGURE 4. RELATIVE RADIATION RESISTANCE OF THERMOPLASTIC RESINS

TABLE 1. EFFECT OF VACUUM ON RADIATION STABILITY OF POLYMERS

Polymer	Effect of Vacuum[a]
Plastics	
Diallyl phthalate	No significant effect
Epoxy	No significant effect
Mylar	Improves stability
Polyamide (nylon)	No significant effect
Polycarbonate	Slight improvement
Polyethylene	Improves stability
Polyvinyl chloride	Decreases stability
Silicone	Improves stability
Teflon	Improves stability substantially
Kynar (polyvinylidene fluoride)	No significant effect
Tedlar (polyvinyl fluoride)	No significant effect
Kel-F (trifluoromonochloroethylene)	Improves stability
Elastomers	
Polyacrylic	No significant effect
Butyl	No significant effect
Hypalon (chlorosulfonated polyethylene)	Decreases stability
Neoprene	No significant effect (conflicting data)
Nitrile	Decreases stability
Polysulfide	No significant effect
Polyurethane	No significant effect
Silicone	No significant effect
Viton A	Improves stability

(a) These effects are only general and individual compositions may behave differently.

TABLE 2. EFFECT OF ULTRAVIOLET RADIATION ON POLYMER STABILITY

Polymer	Effect of Ultraviolet Energy
Plastics	
Mylar	Decreases tensile strength and elongation
Polyamide (nylon)	No significant effect
Polymethyl methacrylate	Surface discoloration and crazing
Polyethylene	Embrittlement
Polypropylene	Embrittlement
Polyimide	No significant effect
Polystyrene	Yellows
Plasticized polyvinyl chloride	Develops tacky and discolored surface
Teflon	No significant effect
Elastomers	
Butyl	Increases tensile strength and elongation
Hypalon (chlorosulfonated polyethylene)	No significant effect
Neoprene	Increases tensile strength, decreases elongation
Nitrile	Decreases tensile strength and elongation
Styrene-butadiene (SBR)	Decreases tensile strength and elongation
Silicone	Surface crazing
Viton A	No significant effect

these combined environments are not any more serious than under atmospheric conditions as far as usefulness in various components is concerned. Some materials such as Teflon have shown better properties in these combined environments. However, it remains a matter of proper compounding and curing and individual study to determine the applicability of the various materials for a particular component use.

Recommendations

(1) The recommendations made in REIC Report No. 21 are still applicable. Although some steps have been made to secure the data recommended in that report, there is still need for more work in these areas.

(2) More data are needed on the amount of damage which may be accrued by elastomeric and plastic materials before failure occurs in the operation of the fabricated component. Information is needed on minimum strength requirements before an item is considered inoperable.

(3) Many of the experimental space flights have been successful and in many of these there has been good use made of polymeric materials. One of the more useful and relatively inexpensive pieces of information which would be of extremely great value would be an accurate and complete compilation of the elastomeric and plastic materials including trade names and specific compositions which have proved successful in these space missions. In cases where these data are of a proprietary nature, sufficient information should be made available so that designers of future vehicles and components can be made aware of the availability of these materials.

(4) Continued work is needed in fundamental studies leading to new and improved polymers having greater resistance to radiation damage.

INTRODUCTION

This report is the first addendum to REIC Report No. 21, "The Effect of Nuclear Radiation on Elastomeric and Plastic Components and Materials" and summarizes data published during the period April 30, 1961, and April 30, 1964, on radiation effects in polymeric components and materials. It also includes effects of vacuum, ultraviolet radiation, and extreme temperatures, where these data are available.

There has been a noticeable decrease in the volume of publications during the period covered in this report. This has been due in part to the amount of information which had been collected previously and to the scope of this earlier information. However, part of the reason for the lack of new information is due to a cutback in the rate of effort and to a change in the overall objectives and philosophy of both Government and industry. There is still a need for work to be continued on determining the effects of radiation at high exposures, the effects of exposure rate on components, high-impulse effects, and the mechanisms of degradation of various elastomers and plastics. In this last area, the amount of degradation which can be tolerated in various component parts before failure in operation needs to be determined.

Because of the interest in space vehicles, the greater portion of the present work being done is concerned with the effects of combined environments such as vacuum and radiation and elevated and cryogenic temperatures and radiation. Because of the interest in space environments, data on the effects of vacuum and temperature are included in this report which do not refer directly to radiation stability. However, it is believed that these data will help to impart an understanding of the effects of radiation in space.

A few new polymers have been developed which are of interest both with respect to their properties and to their possible applications in a space-radiation environment. These are discussed under the individual polymeric materials.

Elastomers and plastics for which no new information was found are not included in this report and the reader is referred to REIC Report No. 21. In this addendum report, components are discussed, followed by the elastomers and then the plastics, arranged alphabetically.

It is often necessary in dealing with radiation exposures to convert from one unit of radiation exposure to another, particularly when comparing various reports. Table 3 lists the conversion factors which have been used by the REIC in making the necessary conversions.

To permit comparison of data from various sources, reported in a variety of units, it is frequently necessary for the REIC to convert to the units recommended in this memorandum. In many cases, insufficient information is presented to permit an accurate conversion. Of the conversion factors listed below, those marked with an asterisk have been adopted by the REIC to be used in such instances. The values are approximately correct for hydrocarbons, assuming an average energy of 1 Mev for the radiations. These values should be used with caution and only in cases where information is not available on materials composition and energy distribution of the radiation to permit an accurate conversion.

TABLE 3. CONVERSION FACTORS

To Convert	To	Multiply By
Rads	ergs g^{-1}	100
Ev g^{-1} (C)	ergs g^{-1} (C)	1.6×10^{-12}
Roentgen	ergs g^{-1} (C)	87.1
Rep	ergs g^{-1} (C)	84.6
Rad (tissue)	ergs g^{-1} (C)	90.9
Rad (water)	ergs g^{-1} (C)	90.0
Mev cm^{-2}(a)	ergs g^{-1} (C)	4.5×10^{-8}
Photons cm^{-2}(a)	ergs g^{-1} (C)	4.5×10^{-8}
Photons cm^{-2}(a)	rep	5×10^{-10}
Rep hr^{-1}(a)	n cm^{-2} sec^{-1}(b)	7.1×10^{4}
Rad (C) hr^{-1}(a)	n cm^{-2} sec^{-1}(b)	1.17×10^{5}
Rem hr^{-1}(a)	n cm^{-2} sec^{-1}(b)	8.3×10^{3}
(nv_o)	rad (C) hr^{-1}	4.58×10^{-6}
n cm^{-2}(a, b)	rads (C)	4.17×10^{-9}
n cm^{-2}(a, b)	ergs g^{-1} (C)	4.17×10^{-7}
(nv_o)	rads (C)	1.06×10^{-9}
(nv_o)	ergs g^{-1} (C)	1.06×10^{-7}

(a) Assumed average energy of 1 Mev.

(b) The term n cm^{-2} sec^{-1} may appear as nv and the term n cm^{-2} may frequently appear as nvt although the terminology is not strictly correct unless the "v" value is specified.

COMPONENTS

Adhesives

Adhesives are available which maintain shear strengths to a gamma exposure of 10^{10} to 10^{11} ergs g^{-1} (C) at room temperature. An epoxy-phenolic adhesive retained excellent shear strength after irradiation at 350 F to an exposure of 10^{11} ergs g^{-1} (C).

In order to retain useful strengths of adhesives as long as possible, it was recommended that adhesive thicknesses of 10 mils or better be used.

In general, vacuum is not harmful to adhesives, but there are exceptions. Tensile shear strengths of several adhesives either remained the same or increased when samples were exposed to a temperature of 200 C in a vacuum. Oxidation appears to be an important factor in the degradation of adhesives at high temperatures. Vacuum irradiation produced no detectable changes or only minor changes in the lap-shear strength of adhesives tested by various investigators.

Information is available on the effects of radiation at various temperatures in air for several adhesives. In general, these maintained their shear strength to a gamma exposure of 10^{10} ergs g^{-1} (C). Studies with structural adhesives have emphasized their stability in space environments, and several are commercially available that are serviceable under the vacuum and temperature conditions encountered in space. However, care must be exercised in choosing adhesives since some compositions may be adversely affected by vacuum. In the use of transparent adhesives for bonding transparent materials, such as polymethyl methacrylate, ultraviolet radiation is a factor to be considered.

Effects of Nuclear Radiation

Hexcell 422-J (epoxy-phenolic) adhesive was tested in the form of lap-shear specimens at room temperature and at elevated temperatures(1). Shear-strength tests were conducted at laboratory temperature (75 F) for samples irradiated at ambient temperatures (110 to 130 F) and at 350 F for the samples irradiated at elevated temperatures. Shear strengths of the samples irradiated at ambient temperature to gamma exposures up to 1.7×10^{11} ergs g^{-1} (C) were not greatly different from the shear strength of the control samples. Samples irradiated at 250 F and 310 F to 6.8×10^{10} ergs g^{-1} (C) and 2.2×10^{11} ergs g^{-1} (C), respectively, stored for 7 days at 350 F and then tested at 350 F, lost approximately 15 per cent and 10 per cent of their shear strength. The control (unirradiated) samples under similar test conditions lost approximately 70 per cent of their shear strength. Apparently heat alone affected the lap-shear strength to a much greater degree than the combined radiation-heat environment. At temperatures above 310 F, the effects of heat alone and heat plus radiation [6×10^{10} ergs g^{-1} (C)] were about equivalent. The shear strength of specimens, both control and irradiated, exposed to 450 F decreased from 2500 psi to about 800 psi. Data are shown in Table 4.

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(1) References appear on page 117.

TABLE 4. SHEAR STRENGTH OF ADHESIVE 422-J LAP-SHEAR SPECIMENS[1]

Gamma, ergs g^{-1} (C)	Neutron n cm^{-2} (E>2.9 Mev)	Irradiation Temperature, F	Irradiation Time, hr	Storage Temperature, F	Storage Time, days	Test Temperature, F	Shear Strength[a], psi
Control		--	--	75	--	75	2,490/51/16
Control		--	--	75	--	350	2,690/102/8
Control		110	33	--	--	75	2,666/160/20
2.5×10^{10}	2.2×10^{15}	110	33	--	--	75	2,782/123/20
Control		140	33	--	--	75	2,742/171/20
9.1×10^{10}	1.0×10^{16}	140	33	--	--	75	2,606/137/20
Control		250	33	350	7	350	734/88/20
6.8×10^{10}	5.9×10^{15}	250	31	350	7	350	2,240/150/16
6.8×10^{10}	5.9×10^{15}	250	31	350	8	350	1,937/[illegible]/4
Control		310		350	7	350	816/30/20
2.2×10^{11}	2.4×10^{16}	310	31	350	7	350	2,400/159/3
2.2×10^{11}	2.4×10^{16}	310	31	350	8	350	1,853/[illegible]/17
Control		--	--	--	--	75	2,542/195/10
5.6×10^{10}	5.2×10^{15}	120	55	--	--	75	2,861/199/20
1.7×10^{11}	1.7×10^{16}	130	55	--	--	75	2,590/180/20
Control		450	55	--	--	450	1,430/136/9
6.0×10^{10}	7.2×10^{15}	445	55	--	--	450	1,280/74/9
Control		445	55	450	7	450	920/83/10
6.0×10^{10}	7.2×10^{15}	445	55	450	7	450	809/78/10

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of an [illegible] observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

The effect of gamma radiation on four adhesives was studied by McCurdy and Rambosek(2). Included were:

EC-1469	A modified epoxy-based adhesive
AF-31	An elastomer-phenolic film adhesive
AF-32	An elastomer-phenolic film adhesive
EC-1639	A modified phenolic adhesive

All of these adhesives are relatively rigid and are used primarily for metal-to-metal bonding. The effects of radiation on overlap shear strengths and on peel strengths in air at room and at elevated temperatures were determined. Also, the effect of adhesive film thickness was studied. In each case, the adhesive seemed to benefit slightly from the additional crosslinking resulting from low orders of irradiation. However, degradation began at an exposure of 5 to 6 x 10^{10} ergs g^{-1} (C). The principal effect of the high exposure [8 to 9 x 10^{10} ergs g^{-1} (C)] was embrittlement.

Figure 5 shows the effect of radiation on the bond performance over a wide temperature range. In most cases the high-temperature performance fell off in a way which paralleled the room-temperature performance. EC-1469 maintained its properties to about 6 x 10^{10} ergs g^{-1}(C), while EC-1639 was relatively unaffected at an exposure of 9 x 10^{10} ergs g^{-1}(C). The elastomer-phenolic films, AF-31 and AF-32, were affected by radiation to a greater extent than were the other adhesives. These rubber-modified films maintained their performance at room temperature up to 4 x 10^{10} ergs g^{-1} (C), but at elevated temperatures, both fell below the MIL-A 5090D, Type II specifications after about 10^{10} ergs g^{-1} (C).

The three elastomer phenolic films varied somewhat in flexibility and, therefore, in the amount of peel strength at room temperature. The most rigid, AF-31, showed the best retention of peel strength when subjected to radiation, but all three adhesives deteriorated to about the same over-all value after 9 x 10^{10} ergs g^{-1} (C). It was thought that some gas formed at the interface.

To determine the effect of adhesive thickness, four bonds were made which varied in thickness from 1.2 mils to 16.1 mils. Peel strength varied from 10 to 30 pounds per inch width. However, under irradiation, all the adhesives lost strength rather rapidly: and at very high doses, there was little significant difference in peel strengths The absolute peel strengths were such, however, that the use of adhesive thicknesses of 10 mils or greater was recommended to retain a useful strength as long as possible. Loss of peel strength was due to embrittlement and, to some extent, to degradation of the adhesive.

McCurdy and Rambosek also tested three composite adhesives for use in bonding honeycomb sandwich structures to metal surfaces. The composite consisted of a flexible adhesive to provide good peel strength at the metal interface and a rigid adhesive to provide wetting and filleting of the honeycomb core structure One of the adhesive systems checked consisted of an EC-1469 epoxy coating on an AF-102 nitrile-phenolic film. The other two composites, AF-200/1593 and AF-202/1593 were not identified as to chemical type. The investigators found that radiation had an extremely detrimental effect on the properties of the rigid adhesive. Peel strength deteriorated rapidly with failure in the fillet area. With high dosage, fillets spalled badly, leaving a relatively clean core surface. It was concluded that these composite adhesive films would not be suitable for high radiation areas in honeycomb sandwich structures where high peel strength is important. Where beam structural strength is a more important function, these adhesives will perform up to 3 to 4 x 10^{10} ergs g^{-1} (C) exposure dose.

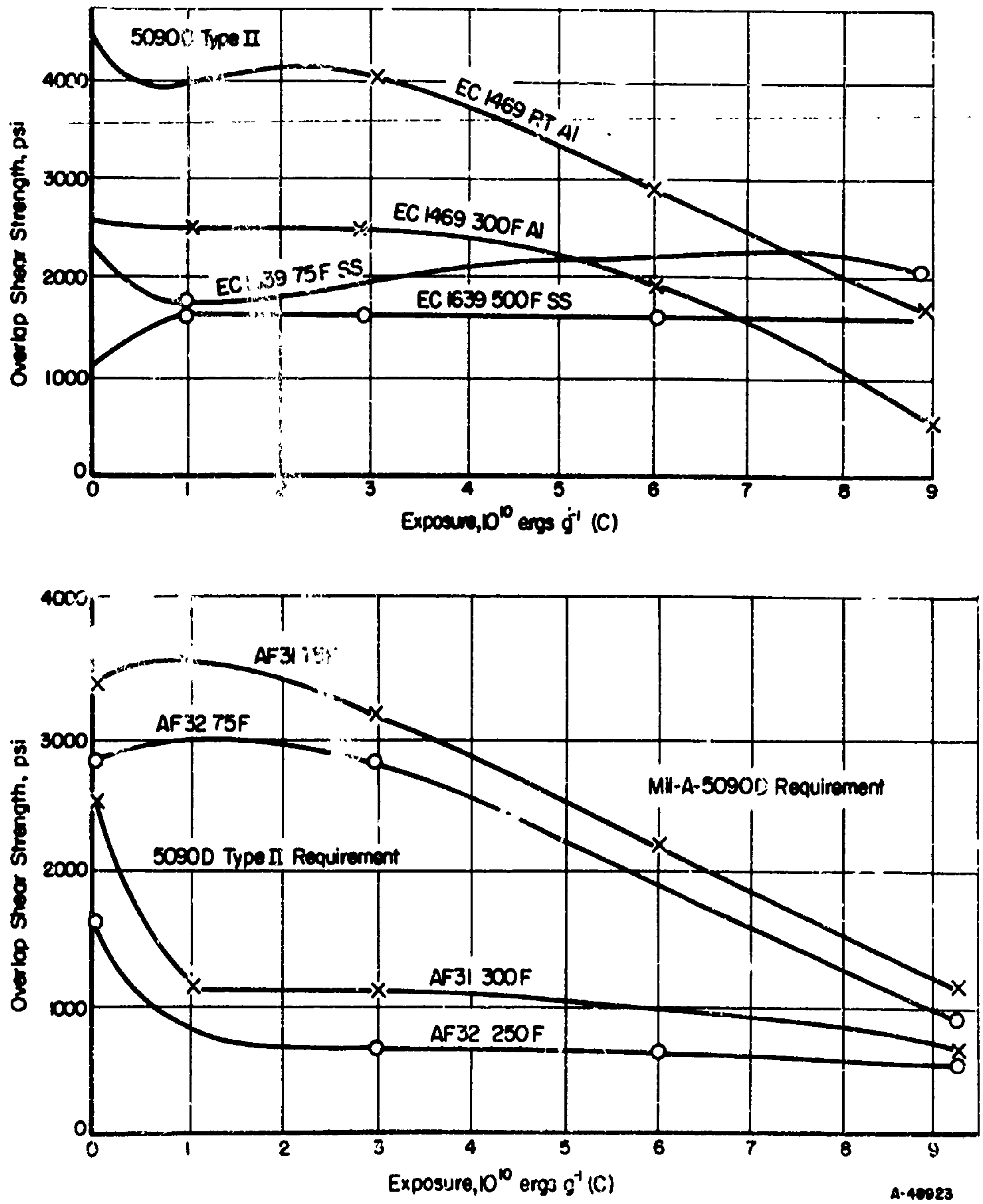

FIGURE 5. EFFECT OF RADIATION ON BOND PERFORMANCE AT VARIOUS TEMPERATURES(2)

Figure 6 shows the difference in performance of the same three adhesive systems under bending loads. It was found that the relatively rigid high-density system EC-1469/AF-102 maintained its performance over the whole range of irradiation. The two composite films, AF-200/1593 and AF-202/1593, deteriorated after an exposure of 3 to 4 x 10^{10} ergs g^{-1} (C), but not quite so fast in the beam structure requirement as they did in the peel test. Failure again was in adhesion to the core.

In an applications test, Litton Systems found that Epon VI did not prove satisfactory for use as an adhesive for bonding a metal spring when the bond was subjected to a radiation exposure of 1 x 10^{11} ergs g^{-1} (C) and a temperature of about 45 C(3). The adhesive appeared to lack dimensional stability, a movement of 1 to 10 mils being sufficient to seriously degrade performance.

Effects of Vacuum and Nuclear Radiation

Podlaseck and Suhorsky(4) and Blackmon, Clauss, and associates(5) reported data on the volatilization of adhesives in a vacuum and in a vacuum-radiation environment. In order to determine the extent of bond weakening of epoxy, epoxy-phenolic, epoxy-polyamide, and silicone adhesives, long-term exposures up to 1100 hours at 93 to 121 C were carried out in vacuum. The samples were exposed to a vacuum of 10^{-6} torr and a temperature of 200 F for 865 hours, followed by an exposure to 250 F and 10^{-6} torr for 312 hours. With the exception of one modified phenolic, supported adhesive film, Aerobond 422, the adhesives were stable in these test environments. The samples were then exposed to 3.4 x 10^{9} ergs g^{-1} (C) in air, followed by exposure to vacuum at temperatures of 2[illegible] F and 300 F, and finally to a cycling (10 cycles) over a temperature range of -80 F to 200 F. As can be seen in Table 5, there was an increase in leakage rate of several of the adhesives after exposure to radiation. However, additional exposure to vacuum and elevated temperatures decreased these leakage rates. It is believed by Blackmon and associates that the gamma radiation induced crosslinking, depolymerization, and chain scission so that low-molecular-weight fragments (e.g., hydrogen, carbon monoxide, carbon dioxide, and methane) were liberated and produced porosity in the glue line. Subsequent exposure to vacuum and elevated temperature permitted flow in the polymers and sealed up the pores.

Kerlin and Smith(6,7) tested structural adhesives for shear strength under combined temperature, radiation, and vacuum environment. Data were included for the following adhesives:

Adhesive	Type	Adhesive	Type
Shell 929	Epoxy	HT-421	Epoxy phenolic
Shell 934	Epoxy	Epon 422 J	Epoxy phenolic
Epon VIII	Epoxy	Metlbond 4021	Nitrile phenolic
Narmco A	Modified epoxy	Scotchweld AF-6	Nitrile phenolic
FM-1000	Epoxy polyamide	FM-47	Vinyl phenolic
Metlbond 406	Epoxy polyamide	APCO 1252 (formerly Hexcel 1252)	Polyurethane
Metlbond 408	Vinyl epoxy polyamide		
Metlbond 302	Epoxy phenolic	Narmco C	Polyurethane

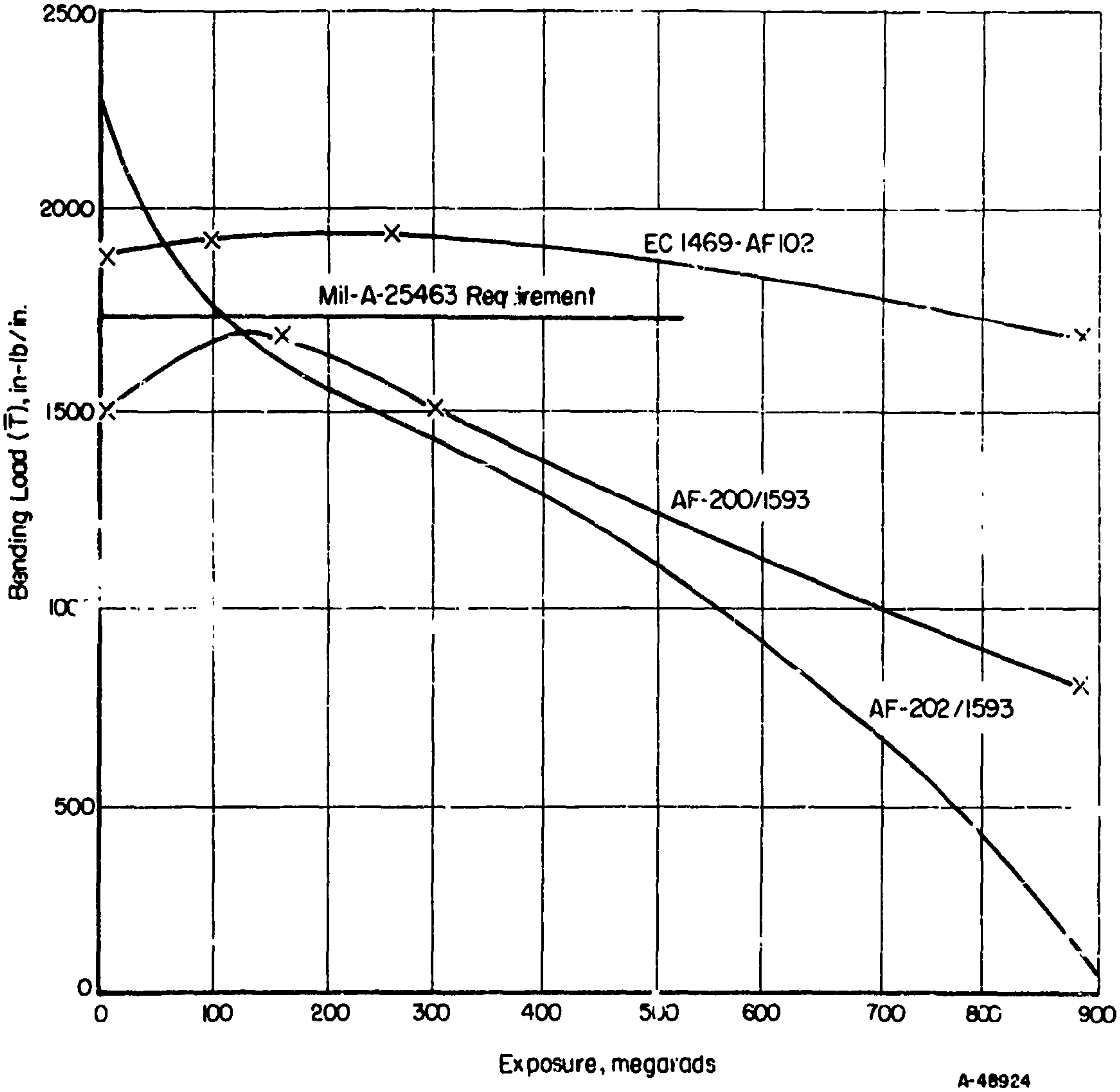

FIGURE 6. EFFECT OF RADIATION ON HONEYCOMB BEAM FLEXURE(3)

TABLE 5. RESULTS OF EXPOSURE TESTS ON ADHESIVES TO VACUUM, ELEVATED TEMPERATURE, AND HIGH-ENERGY RADIATION(4,5)

Adhesive	Chemical Type	Form	Leak Rate, cc/sec (Measured With Helium Leak Detector): After Exposure of 865 Hours at 200 F Plus 312 Hours at 250 F and 10^{-6} mm Hg	After Additional Exposure to 3.4×10^7 Roentgens of Gamma Radiation From Co-60 Source in Air	After Additional Exposure of 50 Hours at 250 F and 50 Hours at 300 F at 10^{-6} mm Hg	After Temperature Cycling at -80 to 200 F (10 Cycles)
Aerobond 422	Epoxy phenolic	Supported film	2×10^{-5}	4.7×10^{-6}	5×10^{-7}	2×10^{-6}
HT-424	Epoxy phenolic	Supported film	Large(a) 10^{-6}(b)	Too large to measure	Too large to measure	--
HT-424-F	Epoxy phenolic	Primer only	10^{-6}	2×10^{-5}	4×10^{-7}	1.3×10^{-6}
EC-1648	Epoxy polyamide	2-pt liquid	10^{-6}	9×10^{-6}	4×10^{-7}	9×10^{-7}
EC-1386	Epoxy	1-pt liquid	10^{-6}	4×10^{-6}	2×10^{-7}	1.3×10^{-6}
Epon 901/B-1	Epoxy	2-pt liquid	10^{-6}	1.4×10^{-7}	2×10^{-7}	2×10^{-6}
Epon 8/A	Epoxy	2-pt liquid	10^{-6}	2.3×10^{-7}	5×10^{-7}	7.5×10^{-7}
A-1	Epoxy	2-pt liquid	10^{-6}	2×10^{-5}	2.5×10^{-7}	9×10^{-7}
Q3-0079	Silicone	1-pt liquid	10^{-6}	1.5×10^{-7}	5×10^{-8}	4.5×10^{-6}

(a) Leak in specimen bonded with HT-424 was detected after the first 21 hours of exposure. This may have been due to a poor seal rather than to the adhesive itself.
(b) Values taken from The Stability of Organic Materials in Vacuum.(4)

The adhesives were irradiated in vacuum to various gamma exposure doses and tested in air after the irradiation in vacuum had been completed. According to Kerlin, the data show that vacuum irradiation produced no detectable change in the lap-shear strength of FM-1000, Metlbond 406, and Epon 422 J. Also, only minor changes were found for Shell 934, HT-424, and APCO 1252. Metlbond 408 decreased 78 per cent in lap-shear strength, Epon VIII and Shell 929 decreased by 12 per cent, and FM-47 decreased by ~~approximately 42 per cent~~. Metlbond 4021 decreased by ~~25 per cent~~ while Narmco C decreased by 48 per cent in shear strengths. (In air, Narmco C lost practically all shear strength when irradiated.) Narmco A increased by 16 per cent in shear strength when irradiated in vacuum. Data are given in Table 6.

Two adhesives, FM-1000 (epoxy polyamide) and Metlbond 302 (epoxy phenolic), were tested for ultimate shear strength in vacuum immediately after irradiation (this was described as a dynamic test). The average ultimate shear strength of the test specimens showed a significant increasing trend from the control tests, through the static irradiation (air) tests, to the dynamic irradiation tests (Table A-1 in Appendix A). This is attributed to a greater rate of crosslinking of the polymer relative to chain scission by oxygen during irradiation. At the lower partial pressures of oxygen in the higher vacuum, the rate of oxygen-induced chain scission is decreased and the relative rate of radiation-induced crosslinking is increased, leading to increased stiffness and strength of the polymers.

Gray, et al.,[8] irradiated lap-shear specimens prepared with epoxy, epoxy-phenolic, vinyl-phenolic, nitrile-phenolic, and glass-supported epoxy-film adhesives. These were irradiated in air and in vacuum (10^{-6} torr) to a gamma exposure of 10^9 ergs g^{-1} (C) at a temperature of 100 F maximum. The specimens were then tested for shear strength at a temperature of -300 F. In all cases, loss in shear strength was small and the original strength of the adhesive bond specimens could be considered for the design of parts to be subjected to the above conditions.

DeWitt, Podlaseck, and Suhorsky[9] reported on adhesives FM-47, a polyvinyl butyral-phenolic adhesive, and HT-424, an epoxy-phenolic exposed to vacuum and elevated temperature. FM-47, after exposure for 3-1/2 hours at 250 F in a vacuum of 4.2×10^{-4} torr, decreased in peel strength by 13 per cent and in shear strength by 7.1 per cent. HT-424, after exposure to 450 F for 4 hours in a vacuum having an ultimate pressure of 5.9×10^{-4} torr, showed a 14.0 per cent decrease in peel strength and 0.6 per cent in shear strength. There was no change in color of the temperature-vacuum exposed samples. Both of these adhesives were evaluated as supported films, the adhesive being coated on an open-weave glass fabric.

Levine[10] noted that oxidation is an important factor in the degradation of adhesives at high temperatures, and he studied adhesive performance in nitrogen. He found that in this environment, serious degradation did not begin with epoxy-phenolic or phenolic adhesives even after an exposure to 600 F for almost 190 hours. Data are shown in Figure 7.

Kerlin[6] reported work done at the George C. Marshall Space Flight Center on the effect of a temperature of 200 C in air and in vacuum on several adhesives. These included:

TABLE 6. AVERAGE ULTIMATE SHEAR STRENGTHS OF ADHESIVES BEFORE AND AFTER IRRADIATION(6, 7)

Adhesive	Type	Shear Strength Before Irradiation, psi	Irradiation in Air, ergs g^{-1} (C)	Shear Strength After Irradiation in Air, psi	Irradiation in Vacuum, ergs g^{-1} (C)	Shear Strength After Irradiation in Vacuum, psi
Shell 929	Epoxy	2264	3.9×10^{10}	2510	2.9×10^{10}	1973
Shell 934	Epoxy	2562	3.9×10^{10}	2840	2.9×10^{10}	2320
Epon VIII	Epoxy	2361	--	--	1.7×10^{10}	2072
FM-1000	Epoxy polyamide	6065	--	--	1.7×10^{10}	6121
		6283	3.9×10^{10}	6086	2.9×10^{10}	6117
Metlbond 406	Epoxy polyamide	4873	1.1×10^{10}	5940	--	--
			4.9×10^{10}	752	--	--
HT-424	Epoxy phenolic	3605	3.9×10^{10}	2599	2.9×10^{10}	3303
Epon 422 J	Epoxy phenolic	2362	--	--	3.9×10^{10}	2452
Narmco A	Modified epoxy	415	3.9×10^{10}	3634	2.9×10^{10}	4959
Metlbond 408	Modified vinyl epoxy nylon	4083	--	--	3.9×10^{10}	896
FM-47	Vinyl phenolic	4315	3.9×10^{10}	3716	2.9×10^{10}	2561
		4180	--	--	3.9×10^{10}	2415
Metlbond 4021	Nitrile phenolic	4370	3.9×10^{10}	3234	2.9×10^{10}	3250
AF-6	Nitrile phenolic	2578	--	--	3.9×10^{10}	2410
APCO 1252	Polyurethane	2743	3.9×10^{10}	3262(a)	2.9×10^{10}	3181
Narmco C	Polyurethane	883	3.9×10^{10}	20.8	2.9×10^{10}	454

(a) At a radiation exposure of 1×10^{10} ergs g^{-1} (C) shear strength given as 3416 and 4212 in two different tests. At a radiation dose of 6×10^{10} ergs g^{-1} (C), shear strength was 5028 psi.

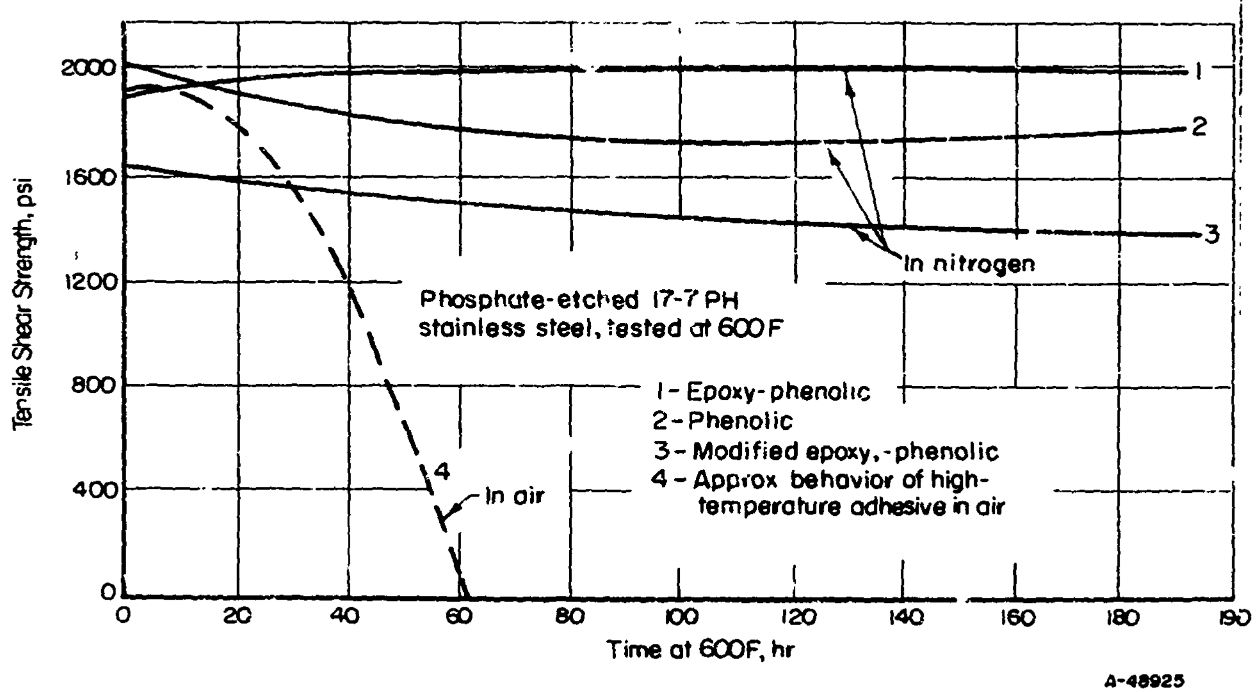

FIGURE 7. EFFECT OF HEAT AGING ON TENSILE SHEAR STRENGTH OF FIVE ADHESIVE BONDS IN NITROGEN VS APPROXIMATE BEHAVIOR IN AIR[10]

Adhesive	Type	Adhesive	Type
Epon VIII	Epoxy	FM-47	Vinyl phenolic
Metlbond 406-1	Epoxy polyamide	Metlbond 302A	Epoxy phenolic
FM-1000	Epoxy polyamide	AF-6	Nitrile phenolic
Epon 422 J	Epoxy phenolic	Metlbond 408	Modified vinyl epoxy nylon

Tensile shear strength of these adhesives either remained the same or increased when samples were exposed to a temperature of 200 C in a vacuum. In most cases, exposure in air to 200 C for the same period of time, 24 hours, caused a decrease in tensile shear strength. The exceptions to this were FM-1000, AF-6, and Metlbond 408. With FM-1000, shear strength increased both in air and in vacuum at the higher temperature, although the increase was greater in vacuum than in air. Data on the AF-6 and Metlbond 408 were incomplete, so no conclusions could be drawn. However, it was evident that these adhesives would withstand elevated temperatures better in a vacuum than in air.

Effects of Nuclear Radiation and Cryogenic Temperatures

Five classes of adhesives were selected for evaluation at cryogenic temperatures on the basis of promising high lap-shear strengths at -65 F and 75 F.(11) These were not subjected to radiation. Lap-shear specimens were tested at -423 F, -320 F, -100 F, and 75 F, utilizing epoxy-nylon adhesives (Metlbond 406, AF-40, and FM-1000), nitrile-phenolic adhesives (Metlbond 4041 and AF-32), epoxy-polyamide adhesives (Resiweld No. 4 and Narmco 3135), an epoxy-phenolic adhesive (Metlbond 302-A), and a polyurethane adhesive (APCO 1219). Selection of adherends for testing was based on the anticipated use of these materials in future missiles and spacecraft, the prevalent use of some of these materials in the Atlas and Centaur, and the promising cryogenic properties of the base materials. The adherends utilized were 0.020-inch EFH 301 CRES (stainless steel), 0.064-inch 2024-T3 bare aluminum, 0.020-inch A-110-AT titanium, 0.125-inch Conolon 506 (phenolic-glass fiber laminate) and 0.125-inch Conolon 527 (polyester-glass fiber laminate). Butt-tensile tests were conducted with 3/4-inch-round stock Type 321 stainless steel and AF-40 epoxy-nylon adhesive.

The epoxy-nylon adhesives resulted in the higher lap-shear strengths with all adherends over the entire temperature range of -423 F to 78 F. Values obtained at -423 F are more than 100 per cent higher than any previously reported values for similar tests. The nitrile-phenolic adhesive gave excellent results over the temperature range of -320 F to 78 F but strength values dropped off sharply at -432 F. The epoxy-phenolic adhesives gave uniform results over the complete temperature range. These results were significantly lower than the epoxy-nylon and nitrile-phenolic adhesives at -320 F, 100 F, and 78 F. At -423 F the epoxy-phenolic is superior to the nitrile-phenolics. Room-temperature-cured adhesives are generally inferior to those that are heat cured. Of the three room-temperature-cured adhesives tested, the polyurethane gave higher lap-shear strengths than the epoxy-polyamides with an aluminum adherend and approximately the same strengths with stainless steel adherends. All the adhesives tested had their highest lap-shear strengths at -100 F.

Gray, et al.,(8) irradiated in vacuum at ambient temperature specimens prepared with epoxy, epoxy-phenolic, vinyl-phenolic, nitrile-phenolic, and glass-supported

epoxy-film adhesives and tested them at -300 F for ultimate shear strength. Results are shown in Appendix A, Figure A-1. The test results indicated that the cryogenic temperature-vacuum environment had no effect on lap-shear strength. Gray noted that specimens prepared with epoxy-phenolic, glass-supported epoxy film, and vinyl-phenolic appeared to be only slightly affected by vacuum. The effect was small enough that the original strength of the adhesive-bonded specimens could be considered in the design of parts for the above conditions. Epoxy and nitrile-phenolic-adhesive-bonded specimens showed no indication of deterioration.

Yasui[12, 13] irradiated one polyurethane-adhesive-bonded and three epoxy-adhesive-bonded test specimens immersed in liquid nitrogen. They were then tested at liquid-nitrogen temperatures. Yasui found no effects of irradiation on single lap-shear or flatwise ultimate strengths for these materials. Data are shown in Figures A-2 and A-3. Narmco 3135, 3M 1469/1968, and Lefkoweld 109 are epoxy adhesives while APCO 1219 is a film-forming polyurethane polymer.

Coatings

When nuclear reactors are used in spacecraft, gamma radiation may be present in large quantities and may become an important design consideration. However, for exposure to the normal elements of the space environment, nuclear radiation does not appear to be so severe a problem as ultraviolet flux.

Several coatings have shown negligible change in α/ϵ ratios as a result of exposure to 10^{9} ergs g^{-1} (C) of cobalt-60 gamma radiation.

Zinc sulfide in a silcone resin vehicle has afforded a very good combination of infrared emission and long service life, in spite of the fact that considerable discoloration developed under ultraviolet irradiation. Zinc sulfide in an acrylic coating matrix also has shown good promise.

Organic coatings were originally used solely for corrosion protection and decoration. Today, coatings used for temperature-control materials, have to survive and function reliably on, and within, spacecraft in a totally new environment. When using coatings in thin films, the optical and physical changes resulting from long exposure to high vacuum, intense ultraviolet radiation, and variable temperatures have to be considered.

Coatings having selective properties can be used to control radiant heat transfer by control of three basic optical properties: (1) reflectance, (2) absorptance, and (3) emittance.[14] In most practical systems, a balance between these three conditions will be used to obtain the desired temperatures as illustrated in Table 7.

Present-day coatings for spacecraft are designed to rely upon passive radiation techniques in which the desired average critical temperature is achieved by properly balancing the absorptivity of the surfaces for solar radiation (α) with their emissivity for infrared radiation (ϵ).

Organic coatings are virtually all very absorptive in the infrared and hence have high emittance. Such a surface is the most stable and efficient to use for long heating periods. The short-wavelength absorption can be readily varied by pigmentation with

TABLE 7. VEHICLE TEMPERATURE CONTROL(14)

Coating	Solar Reflection	Solar Absorption	Emittance	Temperature, F Sphere	Temperature, F Striped Sphere
White	0.82	0.18	0.95	-135	-20
White plus carbon black	0.47	0.53	0.95	-30	32
Flat black	0.03	0.97	0.95	45	85
Flat black plus aluminum	0.05	0.95	0.80	65	120

TABLE 8. ORGANIC MATERIAL RADIATIVE PROPERTIES(14)

Organic Material	α	ϵ	α/ϵ Ratio
White (30% PV zinc sulfide) silicone	0.31	0.77	0.40
Gray silicone	0.53	0.95	0.55
Leafing aluminum in silicone	0.32	0.33	0.98
White lead carbonate (30% PV) silicone	0.46	0.46	1.0
Dull black (vinyl phenolic)	0.93	0.84	1.1

organic and inorganic materials. The organic coatings will have α/ϵ ratios of 1 or less and can be used to give cool or cold surfaces in space (Table 8). It is obvious that the reflectance and absorptance of the pigmented coating varies with the pigment. A leafing aluminum pigment is the most efficient reflector of ultraviolet energy. Several white pigments are superior to leafing aluminum in the visible and near-infrared spectral regions, but are inferior to it as a reflector of ultraviolet energy. Of the nonleafing pigments, basic white lead carbonate is superior to all others in reflecting ultraviolet energy. The white lead pigmented coatings lose much of their efficiency as ultraviolet reflectors when exposed to the simulated space environment. In other regions of the spectrum, zinc sulfide is an excellent reflector of visible and near infrared energy. Other paint formulations use rutile, carbon black, red iron oxide, and chrome oxide green in various amounts as pigments, depending on the α/ϵ ratio desired.

The ultraviolet spectrum of the sun ranges from about 100 A to 4000 A. Virtually all the energy below 3000 A and most of the energy between 3000 and 4000 A is filtered out by the earth's atmosphere. As a result, coatings may absorb 10 to 100 times as much ultraviolet light above the atmosphere as on the surface of the ground on a clear day. Thus, ultraviolet light is definitely a serious radiation problem.

Intense radiation is the second major element of the space environment and can be divided into two broad classes; electromagnetic and particulate. The electromagnetic component of cosmic radiation has low intensity and is rather inconsequential as far as coatings are concerned. When nuclear reactors are used in spacecraft, gamma radiation of high energy may be present in large quantity and can become an important consideration.

The impingement of ionizing radiation in high doses on organic thin films will also result in physical, chemical, and optical changes. However, for exposure to all elements of the space environment, nuclear radiation is not so severe a problem area when compared to ultraviolet flux.

Effects of Nuclear Radiation

General Dynamics[15] and Lockheed Missiles and Space Company[16] are currently engaged in determining the effects of nuclear radiation on the optical characteristics of thermal coatings. This work is presently in progress and only limited data are available. Preliminary results indicate that negligible change in the α/ϵ was experienced by the materials listed below as a result of exposure to 10^9 ergs g^{-1} (C) of cobalt-60 gamma radiation.

Kemacryl White Lacquer No. M49WC17 (Sherwin-Williams)

Kemacryl Black Lacquer No. M49BC12 (Sherwin-Williams)

Leafing aluminum pigment in Kemacryl acrylic vehicle (Sherwin-Williams)

Nonleafing aluminum pigment in Kemacryl acrylic vehicle (Sherwin-Williams)

Fuller 517-W-1 Gloss White Silicone (W. P. Fuller Co.)

Fuller 517-B-2 Flat Black Silicone (W. P. Fuller Co.)

Fuller 172-A-1 Aluminum Silicone (W. P. Fuller Co.)

Fuller 171-A-152 Aluminum Silicone (W. P. Fuller Co.)

Dull Black Micobond L6X962 (Midland Industrial Finisher Co.)

LMSC White Silicate Paint on Al 1100 aluminum alloy

The irradiations are to continue to 10^{11} ergs g^{-1} (C) gamma radiation and to other types of penetrating radiation.

Effects of Ultraviolet Radiation

Fulk and Horr[17] determined the weight loss in vacuum of a number of polymeric materials used in spacecraft. Compositions of the materials are listed in Table 9 while a typical weight loss-versus-time curve is shown in Figure 8. Fulk points out that the "total weight loss until stationary state" and the "time to reach stationary state" are important characteristics of each material. These values should be taken into account when selecting materials for vacuum and/or spacecraft use. Figure 9 shows typical curves for a number of good points.

Carroll[18] reported on the evaluation of materials used on early Mariner spacecraft. The results of screening tests on paints and nonpaint "whites" are listed in Appendix A, Tables A-2, A-3, and A-4, and Figure A-4. The values of init i. . indicated in Table A-4 and Figure A-4 are nominal values for the materials. The aluminized F...P ... showed the least degradation of the materials tested and is the logical choice for the top of the heat shield. For rigid paintable surfaces, either ZW60 or ZW.. zinc sulfide paints (Table A-4) are recommended.

Effects of Ultraviolet Radiation and Vacuum

Wahl, et al.,[19] and co-workers studied the effects of various combinations of ultraviolet radiations (2500 to 7000 A), moderate temperature (290 F), vacuum pressure ($9.0 \pm 7.0 \times 10^{-6}$ torr), and atmospheric pressure (750 ± 20 torr) on a commercial white polyurethane enamel manufactured by Lowe Brothers Paint Company. This enamel consisted of two parts, No. LH-2392 enamel and No. LH-2393 hardener, which were mixed in equal volumes just prior to use. The coating lost weight and changed color from white to light brown. Total spectral reflectance measurements indicated that the absorptivity increased as the ultraviolet radiation intensity and exposure time increased. It was predicted that the long-time, close temperature control of a space vehicle would not be successful using this polyurethane coating.

Clauss, et al.,[20] and Gaumer, et al.,[21] at Lockheed investigated the effect of ultraviolet radiation and vacuum on temperature-control surfaces. For electronic equipment aboard spacecraft to function properly, their temperatures must be maintained within a range of approximately 0 to 60 C. At the present time, white paints are largely used as solar reflectors, but their α/ϵ ratio is about 0.27 and is not low enough for many practical applications, such as attaining low temperature for infrared sensors to operate efficiently. Solar reflectors with an α/ϵ ratio not greater than 0.1 are needed. Table A-5 shows the α/ϵ ratios of a group of representative materials

TABLE 9. SAMPLE COMPOSITION(17)

Material	Manufacturer	Composition
EPO Enamel	Kohler-McLister Paint Co.	Epoxy Paint No. 705-W-132A
606 Line	Kohler-McLister Paint Co.	Alkyd Paint (industrial type)
606 White Line	Kohler-McLister Paint Co.	Alkyd Paint No. 606-W-135
BBRC "Satellite White" Paint (63 W)	Ball Brothers Research Corporation	Satellite Paint having an ϵ of .85 and α of .27-.30
BBRC "One" Paint (80 U)	Ball Brothers Research Corporation	Satellite Paint having a α/ϵ ratio of 1 $\left(\frac{.42}{.42}\right)$

Fuller 172-A-1 Aluminum Silicone (W. P. Fuller Co.)

Fuller 171-A-152 Aluminum Silicone (W. P. Fuller Co.)

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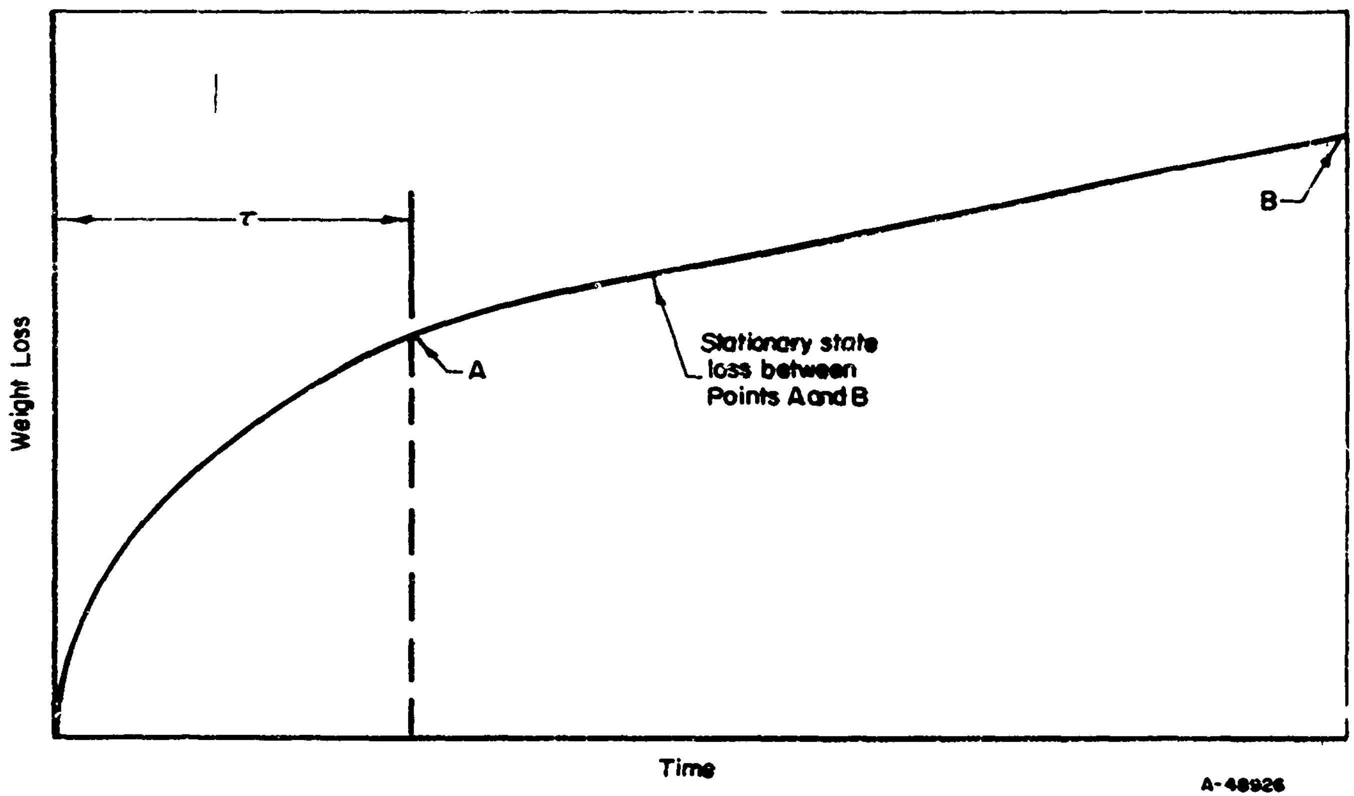

FIGURE 8. CHARACTERISTIC WEIGHT LOSS VERSUS TIME - A TYPICAL WEIGHT LOSS VERSUS TIME CURVE FOR A POLYMERIC MATERIAL IN VACUUM(17)

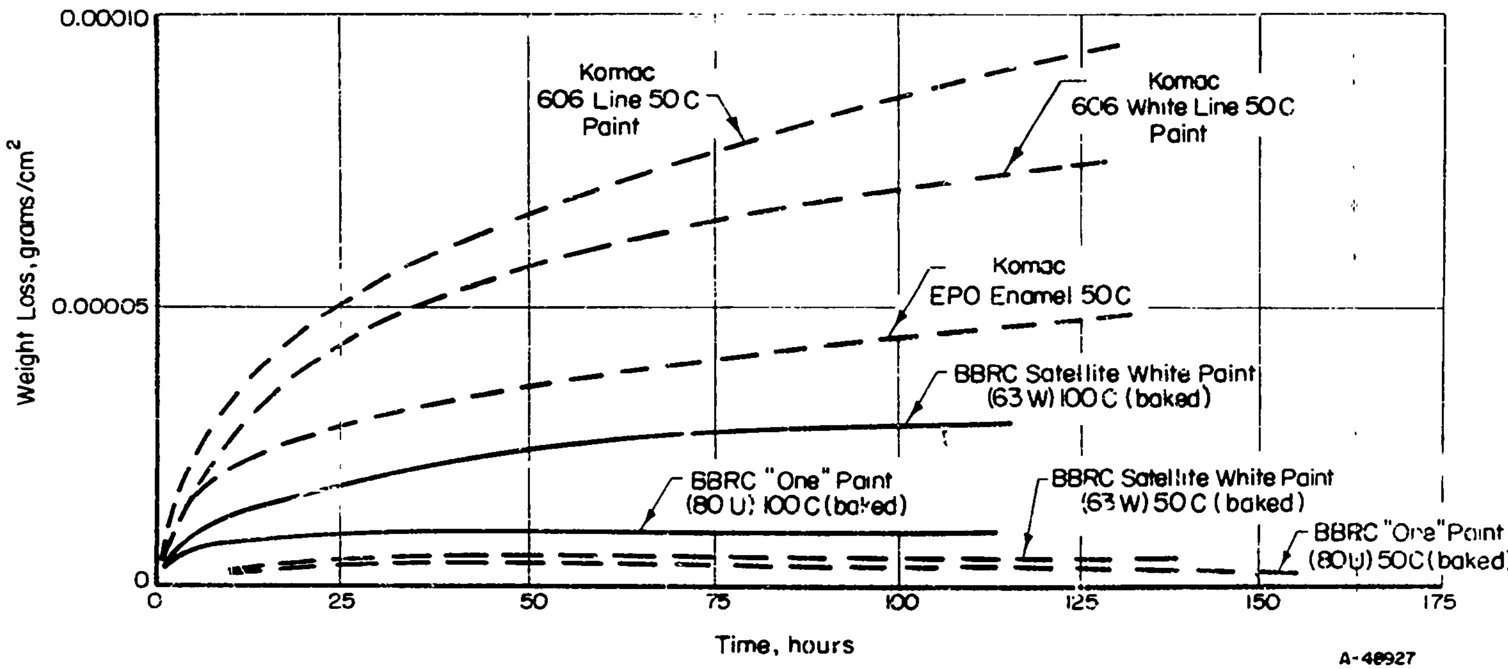

FIGURE 9. PAINTS - WEIGHT LOSS IN VACUUM (PRESSURE <5 X 10^{-6} mm Hg) CURVES FOR A NUMBER OF PAINTS AT 50 AND 100 C[11]

evaluated. The types of surfaces exposed as well as the results of exposure tests are summarized in Table A-6. The designation of the commercial coatings are listed in Table A-7, the compositions of the laboratory-prepared paints are listed in Table A-8. The acrylic-base paints were more resistant to visible yellowing than either the epoxy or silicone-base paints. For many of the organic-base paints, there was an increase of approximately 50 per cent in solar absorptivity (α), while the infrared emissivity (ϵ) remained constant. This 50 per cent increase in the α/ϵ ratio of a surface at room temperature would result in an increase of 57 F in temperature.

Alexander, et al.,[22] studied the effect of very-short-wavelength radiation (1150 to 2000 A) on polymeric films. The percentage weight losses of various coating materials are shown in Figure 10.

Miller and co-workers[23] at Armour Research Foundation tested the stability of white coatings in simulated space environment (approximately 10^{-6} torr vacuum, temperature varying from 150 to 275 F). The results indicated that all synthetic oxide pigments, except zinc oxide, darken appreciably in 100 equivalent solar hours; natural mineral pigments proved more stable. Among the organic binders, a silicone-type material appeared the most promising. Typical results are shown in Table A-9.

The weight loss through volatilization of pigmented coatings after exposure to a simulated space atmosphere for 100 hours (ultraviolet radiation in vacuum of 1×10^{-5} torr) was determined by Cowling.[24] The results are shown in Table A-10.

Effects of Ultraviolet Absorbers

Hormann[25] exposed tailored coatings, some of which contained ultraviolet absorbers such as:

(1) 2, 2'-4,4' tetrahydroxybenzophenone (D50)

(2) Dibenzoylresorcinol (DBR)

(3) 2-hydroxybenzoylferrocene (HBF)

(4) 2-hydroxy-4-methoxy-2'-trifluoromethyl benzophenone (DR1)

to ultraviolet and vacuum. He found that a flat white titanium dioxide-pigmented silicone-alkyd coating showed good vacuum-thermal and ultraviolet-radiation stability. A wide range of α/ϵ values (0.20-0.85) based on this coating are available for various temperature-control conditions. Dispersion of an ultraviolet absorber in a clear film over the basic coating exhibited a protective action in reducing the weight loss through 500 F and in reducing $\Delta\alpha$ at 300, 400, and 500 F.

The black-leafing-aluminum system would provide high α/ϵ values (0.90 to 1.40) due to decreased emittance values with increased leafing-aluminum content. Hormann also indicated that above 400 F, polyurethane systems are inadequate in a vacuum-thermal environment.

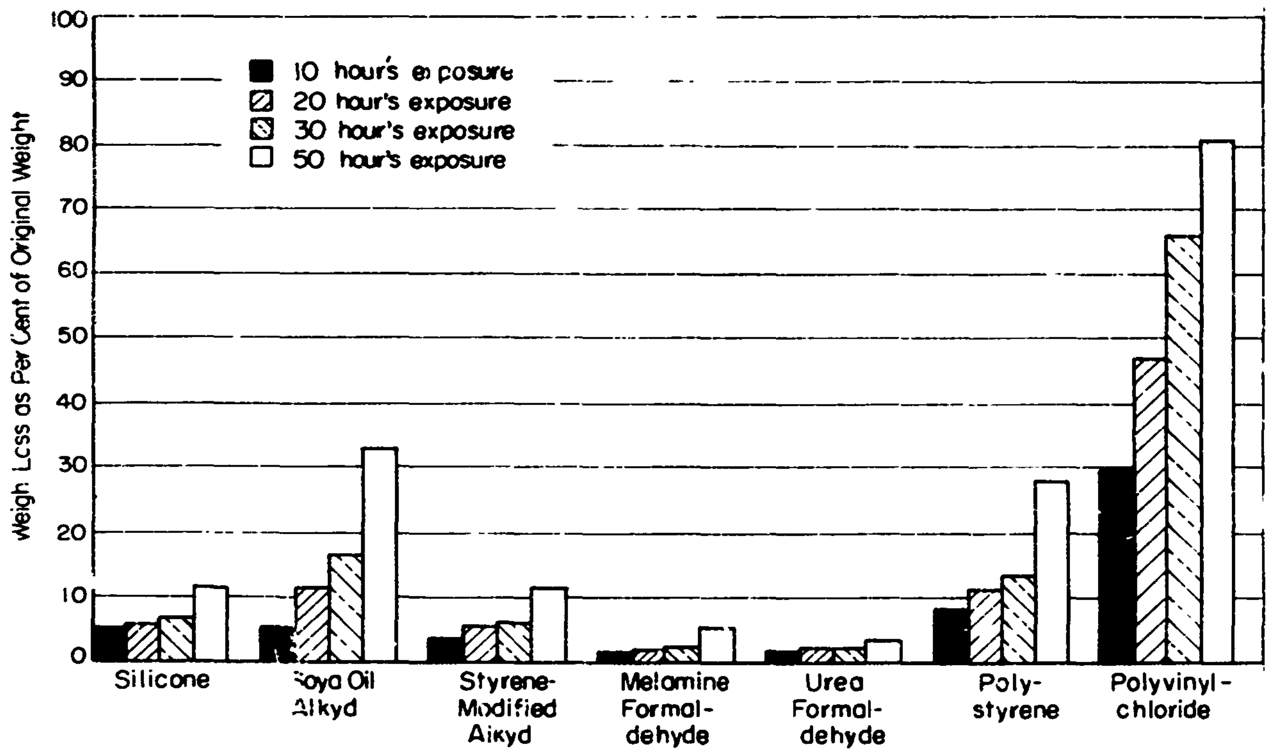

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FIGURE 10. EFFECTS OF NEAR ULTRAVIOLET IRRADIATION ON POLYMER FILMS UNDER NORMAL ATMOSPHERIC CONDITIONS(22)

Field, Cowling, and Noonan[26] found zinc sulfide (Cryptone 800 produced by the New Jersey Zinc Company) in a silicone vehicle afforded a very good combination of infrared emission and long service life, in spite of the fact that considerable discoloration developed under ultraviolet irradiation. Zinc sulfide in an acrylic coating matrix (Acryloid A-10, Rohm & Haas) also showed good promise. In at least one instance, the acrylic formulation proved superior to all the silicone formulations.

Electrical Insulation

Insulation materials such as glass-diallyl phthalate, Formvar wire coating, Silicone DC 997 varnish, polystyrene coil dope, and polyolefin wire insulation have been satisfactory in room-temperature tests to an exposure of 10^{11} ergs g^{-1} (C).

A number of phenolic circuit boards tested have shown no deterioration at 10^{10} ergs g^{-1} (C).

In general, the effects on electrical properties of irradiation of electrical insulation in air and in vacuum are similar.

Polyimide film (Du Pont H-Film) shows excellent temperature and radiation stability in air and in vacuum to at least 10^{10} ergs g^{-1} (C).

In general, permanent changes in electrical properties of polymeric materials with irradiation are minor and the life of the insulation depends upon its resistance to mechanical damage. However, transient effects due to exposure in a radiation flux may cause difficulty. The discussion in this section is limited to the physical properties of some of the more recent insulating materials which have been investigated. A more comprehensive discussion of electrical effects will be found in REIC Report No. 36, "The Effect of Nuclear Radiation on Electronic Components Including Semiconductor Devices", which is being published concurrently with this report.

Data have been obtained on Tedlar (polyvinyl fluoride), Kynar (polyvinylidine fluoride), and H-film (polyimide), some of the newer films which have appeared on the market. Also, limited data on effects of vacuum and radiation, and extreme temperatures and radiation have been collected.

Effects of Nuclear Radiation

Kaufman and Gardner[27] determined the performance characteristics of resistors, capacitors, and insulating materials used for printed-circuit boards or electrical connectors in a nuclear environment. At an exposure of 1×10^{11} ergs g^{-1} (C)[1.67×10^{16} n/cm^2 (E_n>2.9 Mev)], glass-diallyl phthalate was the most suitable material tested as an insulating material for connectors. Melamine, silicone rubber, and phenolic were rated second best because of some degradation in their mechanical properties.

Several laminates were tested for use as circuit-board insulation. Silicone-resin-impregnated Fiberglas was satisfactory as an insulation at an exposure of approximately

10^{11} ergs g^{-1} (C), but the copper circuit could not be adequately bonded to this material. Only slight discoloration of the circuit board occurred owing to irradiation. A phenolic circuit board, 181 Volan A glass fiber impregnated with CTL-91D was exposed to 10^{10} ergs g^{-1} (C) [2.5×10^{15} n/cm^2 (E_n>2.9 Mev)]. No evidence could be found of any discoloration, warping, or blistering, and the copper circuit remained firmly bonded to the board.

Koehler and Pefnay[28] reported polyethylene, Zytel Nylon 33, and polyvinyl chloride as satisfactory insulation materials to an exposure of 10^{10} ergs g^{-1} (C) in air when dry. Litton Systems, Inc.,[3] in work to secure data on the performance of subsystem components and hardware, exposed an LPR-10 drum to the neutron and gamma flux of General Dynamics Ground Test Reactor (GTR). Exposure was to an integrated neutron and gamma exposure of 1.3×10^{16} $nv_f t$ and 1×10^{11} ergs g^{-1} (C) at a temperature of 30 C to 60 C. The specimens were at 45 C during the greater portion of the time. Polymeric materials which were found satisfactory included silicone glass insulation, Formvar magnet-wire coating, Silicone DC 997 varnish, Raychem polyolefin lead-wire insulation, polystyrene coil dope, and mineral filled diallyl phthalate (for the terminal block).

Effects of Elevated Temperature and Radiation

Campbell[29] studied the effect of combined heat and radiation on several magnet-wire-insulation materials, including polyvinyl formal, polyester, silicone, and fluorocarbon enamels and varnishes. He found that the normal service life of some materials was increased by as much as 800 per cent in a combined radiation and thermal environment. He attributes this to a balancing of the chain-scission and crosslinking mechanisms. Tables 10 and 11 show a comparison of the service life of several insulation coatings in a thermal environment and that in a radiation-thermal environment. Radiation exposures varied from 1.8×10^6 ergs g^{-1} (C) hr^{-1} (2×10^4 roentgens hr^{-1}) to 1.6×10^8 ergs g^{-1} (C) hr^{-1} (1.77×10^6 roentgens hr^{-1}).

The normal service life at 160 C of polyvinyl formal was extended by 870 per cent when the material was in a combined thermal-radiation environment as compared with the life in a thermal environment. Several other materials exhibited longer service life in the combined environment. Improvement ranged from 162 per cent for the combination of silicone enamel and silicone varnish at 240 C to 780 per cent for that of a polyester enamel and oil-modified phenolic varnish at 200 C. On the other hand, polytetrafluoroethylene enamel retained less than 1 per cent of its normal service life at 270 C when in a radiation field.

Effects of Vacuum and Radiation

General Dynamics[6,7] irradiated in air and in vacuum electrical insulation materials designated as DC-7-170 (silicone), Geon 2046 and Geon 8800 (polyvinyl chloride), Estane 5740X1 (polyurethane), Kynar (polyvinylidine fluoride), Kel-F-81 (polytrifluoroethylene), Duroid (a Fiberglas-reinforced Teflon), and Mylar (polyester). Physical properties were determined before and after irradiation and the data are shown in Table A-11.

TABLE 10. EFFECTS OF GAMMA RADIATION ON THERMAL LIFE OF MAGNET-WIRE INSULATION[29]

Insulation Material		Exposure Environment								
		(A) Thermal Aging; No Irradiation		(B) Thermal Aging Following Irradiation [Aging Temperature as in (A)]				(C) Combined Environment [Aging Temperature as in (A); Exposure Rate as in (B)]		
Enamel	Varnish	Aging Temperature, C	Average Life, hr	Exposure Rate, mr/hr	Total Exposure, mr	Average Life, hr	Per Cent of Thermal Life	Total Exposure, m	Average Life, hr	Per Cent of Thermal Life
Polyvinyl formal	None	180	280	0.5	210	244	87	281	562	[illegible]
Polyvinyl formal	None	[illegible]30	634	0.5				2750	5507	[illegible]
Polyester	Oil-modified phenolic	200	3,163	0.02	125	2640	84	25	1263	40
Silicone	Silicone	240	[illegible]53	[illegible]	125	315	89	286		162
Modified polyester	Oil-modified phenolic	200	655	0.2	125	722	110	1020	[illegible]	[illegible]
Polytetra-fluoroethylene	Silicone	[illegible]70	10,000	0.02	25	0	[illegible]	1.2	60	[illegible]
Polytetra-fluoroethylene	None	270	10,000	0.02				1.0	53	[illegible]
Modified silicone	None	240	500	0.5				154	307	61

TABLE 11. RESULTS OF COMBINED ENVIRONMENT EXPOSURES IN PROGRESS(29)

Insulation Material: Enamel	Insulation Material: Varnish	Exposure Temperature, C	Normal Thermal-Aging Life, hr	Exposure Rate, mr/hr	Exposure Time at End of Limited Test Period, hr	Per Cent of Normal Thermal Life at End of Limited Test Period[a]
Polyvinyl-formal	None	200	190	0.5	288	200
Polyvinyl formal	None	180	280	0.04	1862	665
Aromatic polyimide	None	300	940	0.5	2650	282
Polyester	Oil-modified phenolic	200	500	0.5	2798	112
Polytetra-fluoroethylene	None	13	>10,000	0.02	1862	<100

(a) Results not final; aging process being continued.

Silicone DC-7-170 increased in tensile strength 144 per cent, while elongation decreased 83.5 per cent when subjected to a nuclear-radiation exposure of 9×10^9 ergs g^{-1} (C) in vacuum. Average weight loss was 0.2 per cent. The color changed from a light [illegible] to a dark brown during the vacuum irradiation. Mechanical properties were more severely affected by the vacuum irradiation than by air irradiation.

Kel F became very brittle with vacuum irradiation [exposure of 10^{10} ergs g^{-1}(C)], one specimen breaking during removal from the vacuum chamber. Weight loss was 0.29 per cent. When irradiated in air to 8×10^9 ergs g^{-1} (C), the specimens crumbled. For polyvinyl chloride (Geon 2046 and Geon 8800), changes were somewhat greater in a vacuum-radiation environment than in an air-radiation environment. At approximately 10^{10} ergs g^{-1} (C), changes in tensile strength were 20 to 30 per cent in vacuum and 5 to 15 per cent in air. Also, elongation decreased by 55 to 75 per cent in air and 80 to 85 per cent in vacuum. Kynar (polyvinylidene fluoride) increased in tensile strength by about 20 per cent when irradiated in air to an exposure of approximately 10^9 ergs g^{-1} (C). In vacuum, the increase was negligible. Change in elongation was greater in vacuum than in air, although there was little change in this property.

Polyurethane and Duroid are less affected by irradiation exposure of 10^9 ergs g^{-1} (C) in vacuum than in air. Mylar increased in tensile strength, but decreased in elongation when irradiated in vacuum. No significant weight loss was noted. This material appears satisfactory for applications in a vacuum-gamma radiation environment to 10^{10} ergs g^{-1} (C). However, it is susceptible to ultraviolet radiation damage.

Kerlin and Smith(6,7) also investigated the physical properties of several dielectric materials when irradiated in air and in a vacuum (10^{-6} to 10^{-7} torr). These included Marlex 6002 (high-density polyethylene), Teflon TFE, Tedlar (polyvinyl fluoride), and H-film (polyimide). Data are given in Table A-12. The polyimide film showed the

highest tensile strength and the greatest stability to radiation both in air and in a vacuum. After 3×10^{10} ergs g^{-1} (C) exposure, tensile strength dropped only from 19,470 psi to 17,903 psi when irradiated in air and to 18,877 psi when irradiated in vacuum. Elongation decreased from 128 per cent to 83 per cent when irradiated in air and to 105 per cent when irradiated in vacuum. Tedlar also showed good stability to radiation both in air and in vacuum when irradiated to an exposure of 10^9 ergs g^{-1} (C).

Effects of Cryogenic Temperatures and Radiation

Mylar C was irradiated at liquid-nitrogen and liquid-hydrogen temperatures.(30) At cryogenic temperatures, there was an increase in tensile strength and a decrease in elongation. At the liquid-nitrogen temperature, gamma irradiation decreased the tensile strength, but not below the original value at room temperature.

The polyimide film, HT-1, was also irradiated at liquid-hydrogen and liquid-nitrogen temperatures.(30) Tensile strength of the polyimide film increased and elongation decreased at this temperature, but the effect of radiation up to 10^{10} ergs g^{-1} (C) was very slight.

Laminates

Combined effects of radiation and vacuum [10^{10} ergs g^{-1} (C) and 10^{-7} torr] have shown no deleterious effects on the strength of various tested laminates except those prepared with Paraplex P-43 and Silicone DC-2104 resins. These decreased in tensile strength when subjected to exposures higher than 10^{10} ergs g^{-1} (C).

Dynalam (glass fiber-phosphonitrillic chloride polymer) shows promise for use at 450 F and an exposure of 6×10^{10} ergs g^{-1} (C).

Epoxy, polyester, phenolic, melamine, and silicone laminates have been investigated as to their behavior in a radiation environment. These do not appear to be adversely affected by nuclear-radiation exposure of 10^{10} ergs g^{-1} (C) and ultraviolet exposures of 2 pyrons for 500 hours (1 pyron = 1 cal/cm^2/min). The polyesters were found to be the more sensitive to ultraviolet irradiation, but may be improved with the incorporation of ultraviolet stabilizers. Phenolics appear to be least sensitive to ultraviolet exposure. Epoxy laminates show improved strengths when tested in a vacuum environment. Present information would indicate that cryogenic temperatures will not be a serious problem with structural laminates.

Effects of Nuclear Radiation

Laminates called Dynalam consisting of 181 glass cloth (A-1100 finish) impregnated with AP-Resin-XHU (a phosphonitrillic chloride polymer) were irradiated for 55 hours at an ambient temperature (120 to 130 F) and at 450 F.(1) Some of these laminates contained an unspecified curing agent and some contained no curing agent. All of them showed excellent radiation stability. The tensile strength of samples irradiated in air at 130 F to an exposure of 1.7×10^{11} ergs g^{-1} (C) and tested at room

temperature did not change more than 5 per cent. The tensile strength of samples irradiated at 450 F to an exposure of 6×10^{10} ergs g^{-1} (C) and tested at room temperature did not change appreciably. This was true for both laminates containing a curing agent and for those with no curing agent. Data are given in Appendix A, Table A-13.

Effects of Vacuum and Nuclear Radiation

DeWitt, Podlaseck, and Suhorsky[9] exposed samples in a vacuum of 10^{-4} to 10^{-5} torr to a temperature of 250 F to 400 F for a 7-hour period. Materials investigated and test results are shown in Table A-14 in Appendix A. Only the phenolic 91 LD-Fiberglas laminate was significantly affected by the vacuum exposure. The compression strength of this material increased by 36.5 per cent. Wahl[19] conditioned specimens of polyester (P-43), epoxy (Epon 815), and phenolic (91 LD) laminates for 2 hours in an air-circulating oven. After being cooled in a desiccator and weighed, the samples were placed in a vacuum oven for 1000 hours. After 6 hours, pressure was 7.2×10^{-6} torr; after 100 hours, it was down to 6×10^{-7} torr, and at the end of 1000 hours the pressure was down to 3×10^{-7} torr. Temperature ranged from 78 to 80 F. After 1000 hours, the samples were reweighed. In all cases loss of weight was less than 0.1 per cent. Data are given in Table 12.

TABLE 12. WEIGHT LOSS OF LAMINATES EXPOSED TO HIGH VACUUM FOR 1000 HOURS[19]

Material	Polyester		Phenolic		[illegible]	
	Sample A	Sample B	Sample A	Sample B	Sample A	Sample B
Original Weight, grams	13.4794	13.6450	15.1660	14.6469	14.1908	14.0570
Weight After Exposure, grams	13.4771	13.6408	15.1526	14.6352	14.1908	14.0570
Loss in Weight						
Grams	0.0023	0.0042	0.0134	0.0117	0.0	0.0
Per Cent	0.02	0.03	0.09	0.08	0.0	0.0

Boundy[31] reports the per cent weight loss at a pressure of 10^{-6} torr and exposure temperatures of 75, 150, and 300 F after periods of 1, 4, and 7 days. Data are given in Table 13.

TABLE 13. WEIGHT LOSS FOR LAMINATES UNDER VACUUM-THERMAL CONDITIONS[31]

(Pressure, 10^{6} mm Hg)

Materials	Weight Loss, per cent								
	Temperature, 75 F			Temperature, 150 F			Temperature, 300 F		
	Time, days			Time, days			Time, days		
	1	5	8	1	4	7	1	4	7
Epoxy glass fiber	0.03	0.06	0.06	0.09	0.30	0.33	0.31	0.56	0.62
Phenolic glass fiber	0.11	0.24	0.29	0.24	0.48	0.55	0.97	1.25	1.32
Phenolic cotton	0.41	0.95	1.14	0.93	1.32	1.36	1.84	1.83	1.89

The epoxy has a lower weight loss than the phenolics. It is believed that part of the weight loss of phenolics is due to the release of water formed during polymerization and which has remained in the laminate.

Podlaseck and Suhorsky[4, 32] show that the effect of vacuum on weight loss of polymers is to decrease the equilibrium weight-loss rate at elevated temperatures. They state that since the weight-loss rate is proportional to the degradation rate, the implication is that the normal rate of degradation observed in air can be considered to consist of two modes: (1) an oxidative degradation which is dependent on the partial pressure of oxygen or water vapor available to the specimen, and (2) a pure thermal degradation which is independent of the surrounding environment. A vacuum does not appear to alter the equilibrium weight-loss behavior of the unmodified crosslinked-resin system used, but seems only to provide an inert environment at temperatures where oxygen increases degradation. Nitrogen and helium can afford the same protection as a good vacuum.

Because the rate of weight-loss increase, with increasing temperature, is less in vacuum than in air, the upper temperature limit for the use of many plastics may actually be increased for extended space exposures in radiation-protected areas.

Gray, et al.,[8] determined the tensile strength of several laminates after exposure to radiation and/or vacuum. Table A-15 lists the materials tested, and Figure A-5 shows the effect of vacuum, radiation, and combined environment on these materials. It may be seen from Figure A-5 that, except for the epoxy glass-fiber material (Scotchply 1009-26, Minnesota Mining and Manufacturing), there was little effect of these environments on the laminates. With the Scotchply materials, the combined radiation [10^9 ergs g^{-1} (C)] and vacuum (10^{-6} torr) environment increased tensile strength; whereas either factor alone slightly decreased this property.

Kerlin and Smith[7, 33] tested nine glass-fabric laminates and one honeycomb laminate for effects of radiation-vacuum environment. These included Mobiloy AH-81, CTL-91-LD, and Conolon 506 (phenolic), Paraplex P-43 and Selectron 5003 (polyester), DC-2104 and DC-2106 (silicone), Epon 828 (epoxy), and HRP Honeycomb (phenolic). Tests indicated that the combined effects of radiation and vacuum [approximately 10^{10} ergs g^{-1} (C) and 10^{-7} torr] have no deleterious effect on the strength of the laminates except for P-43 and DC-2104. Paraplex P-43 lost tensile strength rapidly after 10^{10} ergs g^{-1} (C). At an exposure of 3.1×10^{10} ergs g^{-1} (C) in vacuum, tensile strength decreased by approximately 20 per cent as compared with a loss of 6 per cent when irradiated in air to 3.9×10^{10} ergs g^{-1} (C). Similarly, the tensile strength of Silicone DC-2104 decreased after an exposure of 10^{10} ergs g^{-1} (C) in vacuum. At 2.9×10^{10} ergs g^{-1} (C), tensile strength decreased by 15 per cent. In air, no loss was observed at an exposure of 3.9×10^{10} ergs g^{-1} (C). See Tables A-16 through A-19.

Effects of Nuclear Radiation and Cryogenic Temperature

Yasui[13] irradiated two phenolic-impregnated glass-cloth laminates (Sinewave and Hexcel) in liquid hydrogen to an exposure of 3.2×10^8 to 2.1×10^9 ergs g^{-1} (C). Tensile strength and tear strength were determined while samples were immersed in liquid nitrogen. Exposure to 2×10^9 ergs g^{-1} (C) in liquid nitrogen produced no significant effect on the tensile and tear strengths of either material. Data are given in Figures A-6 and A-7.

Two laminates prepared by Lockheed-Georgia Company for possible hydrogen barriers also were evaluated. Laminate I consisted of two plies of Epon 820-resin-impregnated 116 Fiberglas cloth laminated to 1 ply of aluminized polyester film with the aluminum forming one exterior surface. Radiation results indicate that the strength properties of the material were not significantly affected by exposure to 2.6×10^9 ergs g^{-1} (C). The same radiation exposure produced no statistically significant effects on Laminate II which consisted of one ply of 181 Fiberglas cloth impregnated with ERL 2795/2870 epoxy resin and coated with six thin layers of Elastathane M-50.

Gray, et al.,[8] irradiated phenolic, polyester, epoxy, and silicone laminates in air and in vacuum (10^{-6} torr for 2 weeks) to an exposure of 10^9 ergs g^{-1} (C). These were then tested at a temperature of -300 F. Data are shown in Figures A-8 to A-11 (also compare with Figure A-5). According to Gray, the environmental conditioning improved the strength of epoxy with unidirectional glass fibers and phenolic with glass fabric. However, phenolic with high-silica fabric exhibited a slight degradation in ultimate strength. No trend of improvement or degradation due to environmental exposure was found for the remaining materials.

Kerlin and Smith[7] irradiated Conolon 506 (phenolic) and Paraplex P-43 (polyester) at liquid-nitrogen and liquid-hydrogen temperatures to a gamma exposure of 6×10^{10} ergs g^{-1} (C). No significant change in ultimate tensile strength occurred at the liquid-nitrogen temperature. Although tensile strength increased somewhat at the liquid-hydrogen temperature, this was believed to be due to chemical reactions between the ionized hydrogen and components of the adhesive rather than to the lower temperature.

Effects of Vacuum and Ultraviolet Radiation

Wahl, et al.,[34,35,19] exposed three types of laminates to ultraviolet radiation in vacuum. These included glass-reinforced polyester P-43, epoxy Epon 815, and phenolic CTL-91 LD. The ultraviolet source was either an Osram HBO-109 high-pressure quartz-mercury lamp or Osram HBO-100 W/2 mercury lamp which produce ultraviolet and visible radiation from below 2500 to about 7000 A.

No significant degradation of the laminates occurred when exposed to radiation of 2 pyrons (2 cal/cm^2/min) for periods up to 500 hours. To determine the relative effect of exposure to vacuum and varying intensities of ultraviolet radiation for greater lengths of time, further tests were conducted at 2, 3, 4, 5, and 6 pyrons.

Examination of the specimens after exposure to vacuum and ultraviolet radiation, of 2 and 3 pyrons intensity, for periods of 125 hours showed that the transparent polyester and epoxy laminates became opalescent and the surface facing the radiation became brown. This was not observed with the phenolic laminates since they were relatively dark brown and opaque before exposure. With greater exposure to ultraviolet, the polyester and epoxy laminates became more charred and blistered. The phenolics did not char even with 4, 5, and 6 pyrons of ultraviolet. Compressive and flexural strength data are given in Tables A-20 and A-21.

In summary, Wahl found that pressure showed little or no influence on flexural modulus except with polyester at moderate temperature in the presence of ultraviolet radiation. In all cases, higher temperatures decreased flexural strength. The extent of the influence is greatest with epoxy and least with phenolic. It is greatest in the presence of vacuum without radiation, and least in the presence of radiation at 1 atmosphere of pressure. The presence of radiation generally decreased strength. The effect was most pronounced with polyester at room temperature with 1 atmosphere of pressure. Wahl states that heat or ultraviolet alone, or combined, have the greatest influence on strength properties of the three types of laminates and it is important to separate these environmental elements when determining their effect on plastic materials.

Initial work would indicate that incorporation of an ultraviolet absorber in the polyester resin would be effective in reducing degradation due to vacuum ultraviolet. Tables A-22 through A-24 show the ultraviolet absorbers tried, weight loss, and flexural strengths of laminates after exposure.

Potting Compounds

Potting compounds are available that maintain good dielectric-constant, dissipation-factor, and volume-resistivity measurements before, during, and after irradiation to an exposure of about 10^{11} ergs g^{-1} (C).

For potting compounds to be used in a vacuum-radiation environment, a higher temperature cure is preferred to a room temperature cure. Solvent systems are generally not satisfactory because they tend to be gaseous as a result of entrapped solvent; this leads to porosity.

Potting compounds have been found satisfactory for use in vacuum at 170 F to a gamma exposure of 10^{10} ergs g^{-1} (C).

Effects of Gamma Radiation

According to Dexter and Curtindale[36] Dow Corning R-7521 (silicone resin) combined with inorganic fillers such as silica sand or zirconium orthosilicate showed no apparent degradation of physical properties after irradiation exposures of 5×10^{10} ergs g^{-1} (C) (500 megarads) at 23 C or after 10^{10} ergs g^{-1} (C) and 2650 hours at 200 C. Because of its outstanding thermal endurance and radiation resistance, this system is considered an ideal potting material for such equipment as canned motor pumps and reactor-control-rod drives. Figure 11 shows the effects of combined heat and radiation on the electrical properties of R-7521 silicone resin.

Several potting compounds were investigated by Armstrong.[37] These included:

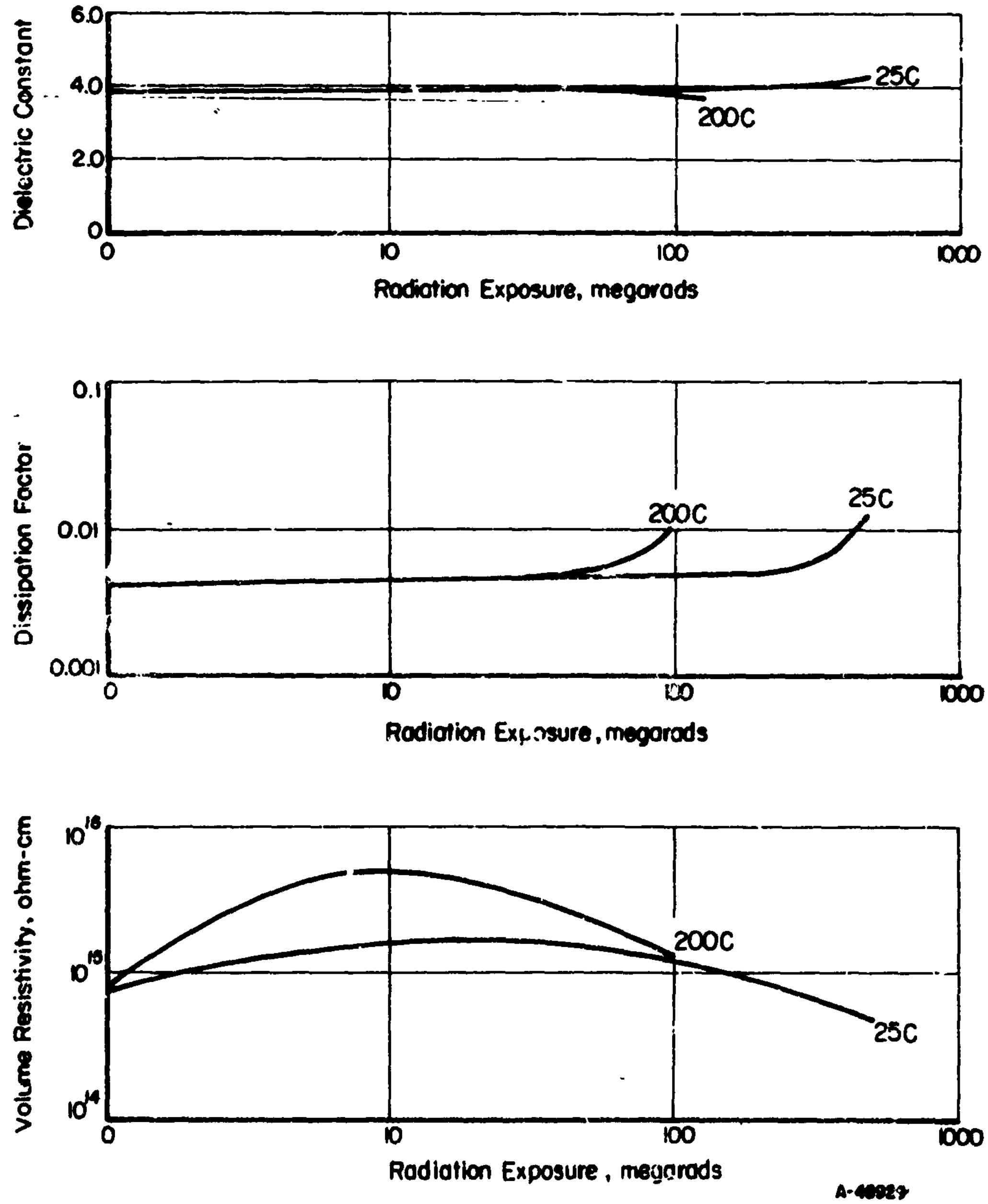


FIGURE 11. EFFECTS OF GAMMA RADIATION ON ELECTRICAL PROPERTIES OF SILICA SAND IMPREGNATED WITH DOW CORNING SOLVENTLESS SILICONE RESIN R-7521(36)

Scotchcast No. 3	Minnesota Mining and Manufacturing Co.
Stycast 2651 MM	Emerson and Cuming
RTV-501	Dow Corning
Epon 828/D	Shell Chemical Co.
Insulating Lacquer 1162 A/B	Dennis Chemical Co.
12-007	Hysol Corp.
Stayfoam AA402	American Latex
EG 758 T	Mica Corp.
Scotchcast Foam Resin No. 603	Minnesota Mining and Manufacturing Co.

Insulation resistance measurements were taken before, during, and after irradiation. Resistances of the samples were found to be dependent on the exposure [exposure rates varied from approximately 10^4 ergs g^{-1} (C) hr^{-1} to 10^8 ergs g^{-1} (C) hr^{-1}]. The greatest change occurred in the Mica reference sample; the potting materials served to decrease the rate effects in the other samples. RTV-501 showed an appreciable change in insulation resistances at the higher exposure rates, as did Dennis Insulating Lacquer 1162 and American Latex Stayfoam AA-402.

Bendix Corporation measured dielectric constant, dissipation factor, and volume resistivity before, during, and after irradiation of seven types of epoxy resins.(38) Exposure was about 10^{11} ergs g^{-1} (C) or 1.1×10^{16} nv_ft. Of the seven tested, five were considered as stable potting and insulating materials at the exposure of the test. These included:

Maraset 622-E
K [illegible] -M
[illegible]ish 42[illegible] A
Scotchc[illegible]t 5
Scotchcast 212

Effects of Radiation and Vacuum

Cure is an important factor with potting compounds subjected to the radiation and vacuum conditions of a space environment. A higher-temperature cure is preferred to a room-temperature cure. Solvent systems are generally not satisfactory as they tend to dissolve the insulation of imbedded wire and retain residual solvent which leads to porosity.

Blackmon, et al.,(5) determined the effect of vacuum (10^{-7} torr) and radiation on a number of potting compounds at a temperature of 170 F. Some of the materials were exposed to 10^{10} ergs g^{-1} (C) gamma radiation in air. Table 14 summarizes the overall performance of the materials. No large changes in hardness or dielectric constant resulted. The greatest variations were in weight loss and, consequently, dimensional stability. Two of the materials, Epocast 202/9615 and Hysol 12-007 A/B were satisfactory on exposure to vacuum and gamma radiation. According to Clauss(39), the Hysol showed excellent stability, but cure shrinkage was greater than 2 per cent and shrinkage during exposure to vacuum at 170 F was 4.5 per cent. Three materials that were found satisfactory after exposure to vacuum at 170 F were not subjected to radiation exposure. These included a polyurethane, PRC 1535 A/B (Products Research Company), a silicone elastomer, DC 502/501 (Dow Corning Corp.), and an epoxy-polyamide, Epibond 1210/9615 (Furane Plastics Co.).

TABLE 14. ENCAPSULATING MATERIALS[39]

Material Designation	Type	Manufacturer
	Satisfactory After Both Types of Exposure	
EPOCAST 202/9615	Epoxy-polyamide	Furane Plastics Co.
HYSOL 12-007 A/B	Epoxy (flexible)	Hysol, Inc.
	Satisfactory After Vacuum-Temperature Exposure (no radiation exposure)	
PRC 1535 A/B	Polyurethane	Products Research Co.
DC 502/501	Silicone (elastomer)	Dow-Corning Corp.
EPIBOND 1210/9615	Epoxy-polyamide	Furane Plastics Co.
	Unsatisfactory	
DENNIS 1162	Epoxy (solvent system)	Dennis Chemical Co.
PRC 1201-Q	Polysulfide	Products Research Co.
ECCOSEAL HI-Q	Polystyrene (solvent system)	Emerson and Cuming, Inc.
EPON 828/D	Epoxy	Shell Chemical Co.
HYSOL 3X	Epoxy (filled)	Hysol, Inc.

Vacuum-Temperature Exposure: 48 hours at room temperature followed by 96 hours at 170 F in a vacuum of 10^{-6} torr

Radiation Exposure: 10^8 roentgens total gamma radiation in air at room temperature at a dose rate of 10^6 r/hr

Kerlin and Smith[6,7] studied the effect of radiation and vacuum on several silicone and epoxy potting compounds. These included:

Epon 828/Z	Epoxy
Silicone DC-R7521	Silicone
Scotchcast 212	Epoxy
RTV-501	Silicone
RTV-60	Silicone elastomer
EC-2273	Fluorinated elastomer

The ultimate compressive strength of Epon 828/Z increased approximately 6 per cent when subjected to a radiation exposure of 10^{10} ergs g^{-1} (C) at a pressure of 2×10^{-6} torr. This change is not considered to be significant. There was no change in the weight of the material and its color changed from amber to dark brown. Silicone DC-R7521 did not change significantly in weight or compressive strength at a radiation exposure of 9×10^{9} ergs g^{-1} (C) and a pressure of 2×10^{-6} torr, but changed from a straw color to dark brown. Data are given in Table A-25 in Appendix A.

RTV-60, a silicone elastomer, was exposed to radiation under static and dynamic conditions. The compressive strength was found to increase for a deflection of 0.02 inch after an exposure of 8.6×10^{9} ergs g^{-1} (C) in vacuum. Samples exposed under dynamic conditions required a 76 per cent increase in load to compress them 0.02 inch. Statically exposed samples tested several weeks later required a 386 per cent increase in load. A load of 1549 psi was required to compress the static irradiated sample 25 per cent as compared to a value of 203 psi for the control, a change of 66[illegible] per cent. Data are given in Table A-26 and Table 15.

The irradiation in air of Scotchcast 212 (epoxy) and EC-2273 (a fluorinated elastomer) had little effect on their properties. Irradiation in vacuum caused compressive strength of the Scotchcast to increase by almost 50 per cent. A small increase was noted for EC 2273. With RTV-501 silicone, radiation both in air and in vacuum increased compressive strength. However, in vacuum, the increase was more noticeable. Data are given in Table A-27.

Seals, O-Rings, and Gaskets

Elastomers which have shown promise for use as seals, O-rings or gaskets for use in a radiation environment include natural rubber, SBR, nitrile rubber, some polyurethanes, neoprene, Viton A and B, and silicone elastomers.

For temperatures above 300 F, Viton A, Kel-F, nitrile rubber, and silicone elastomers may be considered.

Elastomers which have shown promise when irradiated to 10^{10} ergs g^{-1} (C) at room temperature include natural, SBR, nitrile, neoprene (if not immersed in water), and some polyurethane rubbers.

At elevated temperatures, the most radiation-resistant elastomers appeared to be satisfactory to 10^{9} ergs g^{-1} (C).

The addition of antirads improved somewhat the stability of nitrile, neoprene, SBR, and natural rubbers. The antirads increased service life by about one order of magnitude.

TABLE 15. EFFECT OF NUCLEAR RADIATION IN VACUUM ON POTTING COMPOUNDS(25)

Category	Trade Name	Gamma Dose [ergs/gm(C)]	Vacuum (torr)	Specimen Configuration	Measured Property	Per Cent Change in Measured Property
Potting Compounds	Epon 828/Z	1.0×10^{-10}	2×10^{-6}	Compression disks	Ultimate compressive strength	[illegible]
					Weight change	
	DC R-7521	9.0×10^{9}	2×10^{-6}	Compression disks	Ultimate compressive strength	
					Weight change	
	RTV-60	8.6×10^{9}	3×10^{-7}	Compression disks	Compressive strength at 25%	+
					Compressive strength at 0.02 inch	[illegible]
					Weight change	

Nitrile rubber is not seriously affected by radiation either in air or in vacuum to an exposure of 10^9 ergs g^{-1} (C). At 10^{10} ergs g^{-1} (C), the effect of irradiation is about the same in air as in vacuum. Irradiation of neoprene to 10^9 ergs g^{-1} (C) has about the same effect in vacuum as in air. Radiation effects on Viton-B appeared to be similar whether irradiated in air or in vacuum.

Effects of Nuclear Radiation

Morris and Caggegi[40] investigated 24 rubber vulcanizates and 93 antirads in an effort to develop rubber gaskets which would be resistant to nuclear radiation. The vulcanizates were exposed to a gamma exposure of 10^{10} ergs g^{-1} (C) at a temperature of 75 F. Elastomers examined included natural, styrene-butadiene, acrylonitrile, acrylic, neoprene, vinylpyridine, polyurethane, silicone, fluorinated silicone, and Viton-A. Using compression set as the criterion for behavior as a gasket material, the elastomers which were the most satisfactory were natural rubber, styrene-butadiene containing 23.5 per cent styrene polymerized at 41 F (Synpol 1500), and nitrile rubber (Hycar 1072). It was found that the resistance to gamma irradiation of styrene-butadiene rubber was improved if it was cured with dicumyl peroxide instead of sulfur.

Genthane S, a polyurethane, was rated as one of the best vulcanizates, but Adiprene C, also a polyurethane, was questionable. Some of the specimens of the latter, including the control, hot-compression set, and irradiated samples, shattered while compressed. Apparently, the strength of this vulcanizate was marginal. Silicone vulcanizates had a high compression set before irradiation and showed large decreases in Mast indentation* after irradiation. Irradiation caused the Philprene VP-25, Viton A-H , and Silastic LS-53 specimens to corrode the aluminum plates holding them in compression.

Table 15 shows the compression set and the decrease of Mast indentation of several vulcanizates after irradiation. The figures given are the differences between the irradiated values and the original values.

The radiation resistance of the vulcanized rubbers with respect to compression set can be improved by compounding with certain antioxidants, antiozonants, or with certain chemicals containing aromatic rings or condensed ring structures. These are discussed in the section on antirads.

In studies to determine the extent to which antirads can protect O-rings, Born and Associates[41] investigated the effect of the more promising antirads in nitrile, nitrile/styrene-butadiene (90/10), neoprene, and Viton-A premium-quality compounds used currently in commercial O-ring seal production. They found that on the basis of absolute postirradiation property values as well as per cent retention of initial values, the nitrile rubber compound (NBR) plus 5 phr of Stabilite-FLX was the most promising all-around candidate rubber compound of this group for O-ring seals for radiation service. This formulation is compounded by Precision Rubber Products Corporation.

*Mast indentation is the depth of penetration of a 0.125-inch hemispherical indentor into the sample with a 1000-gram weight resting on the indentor. Readings are taken after 1 minute and are expressed in hundredths of a millimeter. This test utilizes the Mast Indentometer Model 650-2, but otherwise it is the same test as ASTM D531-56, "Indentation of Rubber by Means of the Pusey and Jones Plastometer".

TABLE 16. CHANGE IN COMPRESSION SET AND MAST INDENTATION OF ELASTOMERS DUE TO GAMMA RADIATION[40]

Rubber	Compression Set due to Radiation, %	Decrease of Mast[a] Indentation due to Radiation
Adiprene C	55	12
Silastic S2048	59	174
Silicone W96	71	185
Synpol 1500	74	41
Philprene VP-25	77	62
Natural	78	42
Genthane S	79	26
Hycar 1071	79	55
Hycar 1041	80	49
Hycar 1042	80	39
Hycar 2001	81	51
Hycar 1001	82	43
Synpol 1000	82	46
Naugapol 1504	83	45
Synpol 8000	83	42
Naugapol 1023	84	57
Hycar 1002	84	43
Hycar 1043	84	48
Neoprene WRT	85	59
Hycar 1014	88	61
Hycar 4021	89	63
Silastic LS-53	98	97
Viton A-HV	100	44

(a) Mast indentation is the depth of penetration of a 0.125-inch hemispherical indentor into the sample with a 1000-gram weight resting on the indentor. Readings are taken after 1 minute and are expressed in hundredths of a millimeter. This test utilizes the Mast Indentometer Model 650-2, but otherwise it is the same test as ASTM D531-56, "Indentation of Rubber by Means of the Pusey and Jones Plastometer".

General Dynamics[1] irradiated four O-ring formulations manufactured by Precision Rubber Products Corporation (PRP). Three of the formulations were developed in a cooperative program by B. F. Goodrich Co. and PRP to develop radiation-resistant O-ring compounds. The fourth was a standard PRP Viton-B formulation. Data were given for a neoprene rubber containing 5 parts Antiox 4010 and for Viton B. These materials when irradiated at 375 F in air and in fluid maintained considerable tensile strength and elongation. Data are given in Table 17.

Lewis[15] at General Dynamics irradiated an SBR rubber and a nitrile rubber composition developed by Goodrich and Precision Rubber Products Companies. Both contained an antirad to improve radiation resistance. These compositions appeared to be serviceable to a radiation exposure of 10^{10} ergs g^{-1} (C). (See Tables 18 and 19.)

TABLE 17. ULTIMATE PROPERTIES OF PRECISION RUBBER PRODUCTS CORPORATION O-RING COMPOUNDS 2277 SPECIAL AND 19007[1]

Compound	Exposure: Gamma, ergs g^{-1} (C)	Exposure: Neutron, n cm^{-2} (E>2.9 Mev)	Irradiation Time and Temperature, hr/F	Medium	Tensile Strength[a], psi: No. 222 O-Rings	Tensile Strength[a], psi: Tensile Specimens	Ultimate Elongation[a], %: No. 222 O-Rings	Ultimate Elongation[a], %: Tensile Specimens
2277	Controls	Controls	5/75	Air	2638/140/5	2795/233/2	372/23/5	523/-/1
Special	1.2×10^9	2.3×10^{14}	5/75	Air	2339/158/5	26[illegible]4/146/3	287/14/5	362/11/3
(neoprene								
containing	Controls	Controls	5/375	Air	1499/234/3	1379/102/3	160/21/3	144/8/2
5 phr	9.1×10^8	1.1×10^{14}	5/375	Air	788/60/5	1075/75/3	65/5/5	69/3/3
Antiox								
4010)	Controls	Controls	5/75	Oronite 8515	2584/82/3	2572/174/3	338/11/3	430/54/3
	1.2×10^9	2.3×10^{14}	5/75	Oronite 8515	1771/216/5	2389/110/3	227/23/5	323/14/3
	Controls	Controls	5/375	Oronite 8515	1631/87/3	1860/146/3	213/8/3	284/8/3
	9.1×10^8	1.1×10^{14}	5/375	Oronite 8515	1247/454/5	2145/203/3	142/28/5	212/17/3
19007	Controls	Controls	5/75	Air	1984/89/3	2021/135/3	254/23/3	305/1.2/3
(Viton-B)	1.2×10^9	2.3×10^{14}	5/75	Air	2041/181/3	2149/312/3	141/5/3	149/12/3
	Controls	Controls	5/375	Air	2024/57/3	2061/159/3	254/8/3	282/20/3
	1.1×10^9	2.[illegible] $\times 10^{14}$	5/375	Air	1131/72/3	1285/55/3	146/5/3	191/7/3
	Controls	Controls	5/75	4P3E fluid[b]	1973/44/3	1951/116/3	256/4/3	293/35/3
	1.2×10^9	2.[illegible] $\times 10^{14}$	5/75	4P3E fluid	1937/180/5	2319/154/3	138/7/5	171/9/3
	Controls	Controls	5/375	4P3E fluid	1863/141/3	2005/181/3	259/10/3	307/34/3
	1.1×10^9	2.9×10^{14}	5/375	4P3E fluid	1818/[illegible]9/4	1844/176/3	164/6/4	187/14/3

(1) *Data are given as* $\bar{x}$/*S. D. /n, where* $\bar{x}$ = average value, S. D. = standard deviation of an individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S. D.

(b) 4P3E – fluid-mixed isomers of phenoxyphenyl ether.

TABLE 18. SUMMARY OF EFFECT OF IRRADIATION AT AMBIENT TEMPERATURE ON PRPC-O-RING COMPOUND 1387[15]

Gamma Exposure, ergs g^{-1} (C)	Specific Gravity at 25 C		Specific Gravity at 25 C		Compression Set[c], %	Hardness, Shore A		Tensile Strength[d], psi	Ultimate Elongation, %
	Before	After[a]	Before	After[b]		Before	After		
0					5.63	70.2	70.4	2701.8	342.3
4.9×10^{8}	1.250	1.252	1.251	1.243	16.96	70.2	71.4	2512.3	300.7
1.8×10^{9}	1.249	1.253	1.251	1.249	36.91	70.4	71.0	2621.4	290.7
3.6×10^{9}	1.249	1.254	1.251	1.245	55.19	70.2	73.2	2809.1	266.7
1.2×10^{10}	1.250	1.258	1.252	1.25[illegible]	82.96	69.6	82.6	3206.8	164.0
3.5×10^{10}	1.250	1.267	1.253	1.257	94.44	70.6	92.4	4128.3	64.0
1.6×10^{11}	1.244	1.293	1.254	1.280	--	--	--	6018.7	(e)

(a) After irradiation in air.
(b) After irradiation in ASTM No. 3 oil. Total oil soak time, 171 hours.
(c) Total time in compression for all specimens, 310 hours.
(d) Tensile values are average for 15 samples; all others are average for 5 samples.
(e) Broke immediately; elongation could not be measured.

TABLE 19. SUMMARY OF EFFECT OF IRRADIATION AT AMBIENT TEMPERATURE ON PRPC O-RING COMPOUND 4387(15)

Gamma Exposure, ergs g^{-1} (C)	Specific Gravity at 25 C		Compression Set(a), %	Hardness, Shore A		Tensile Strength(b), psi	Ultimate Elongation, %
	Before	After		Before	After		
0			9.04			1890.6	449.3
4.9×10^8	1.164	1.172	14.42	64.6	64.4	2014.1	453.3
1.8×10^9	1.166	1.173	27.88	65.0	65.0	2003.2	427.3
3.6×10^9	1.165	1.157	43.26	65.0	67.4	1811.2	339.4
1.2×10^{10}	1.162	1.160	74.95	65.0	75.6	1779.7	209.5
3.6×10^{10}	1.163	1.184	89.77	64.8	86.4	1749.2	65.5
1.6×10^{11}	1.160	1.211	--	--	--	3601.8	18.3

(a) Total time in compression for all specimens, 310 hours.
(b) Tensile values are average for 15 samples; all others are average for 5 samples.

Koehler and Pefhany[28] tested a gaging system for reactor pressure tubes designed to measure diameter, surface defects, wall thickness, and straightness in a defuelled, drained channel during periods of reactor shutdown. The ultrasonic crystal used to trace the wall contour required a water coupling to the tube wall and, therefore, some of the O-rings were wet or immersed in water during the testing of the gaging system. As a result, some of the O-ring materials were tested wet and some dry, depending on the location. The neoprene O-rings were found to be satisfactory to a radiation exposure of approximately 10^{10} ergs g^{-1} (C) both wet and dry. Although the O-rings had hardened, they were considered satisfactory for this application. Silicone rubber O-rings (Armet Green and Grey, and Linear White) and a white Teflon O-ring were considered satisfactory when dry, but they hardened considerably when wet.

Effects of Vacuum and Nuclear Radiation

Gamma-radiation effects were determined by subjecting components containing the seals to nuclear radiation. Solenoid valves, check valves, relief valves, actuators, ball valves, and regulators were subjected to 2 weeks in a vacuum with the temperature cycled daily from -175 to +50 C. They were then subjected to radiation exposure in air and finally to a repetition of the vacuum exposure. Although the effects of environment on the seals in these components were not given directly and are not strictly comparable, it would appear that neoprene, Viton-A, Kel-F, and some Teflon seals were satisfactory. Butyl rubber, nitrile rubber, and other Teflon seals were adversely affected and thus were not satisfactory.

Elastomer sealing materials within a solenoid changed in hardness or size, thereby increasing the mechanical forces required to actuate the valve. This is illustrative of the type problems encountered. Leakage rates of components with elastomer seals and seats generally increased as a result of the combined environmental exposure testing.

Kerlin and Smith[6,7] evaluated Viton-B, nitrile rubber, neoprene, and natural rubber as O-rings. These materials were subjected to nuclear-radiation exposure and to vacuum. Data are given in Tables A-28 through A-31, Appendix A. Table A-28 shows the data for O-rings which were irradiated in vacuum or in air and tested in air. These were described as being static tests. Tables A-29 and A-30 contain data for materials irradiated in vacuum and tested in vacuum. These were described as being dynamic tests.

Examination of Table A-28 will show that nitrile rubber (Parker Compound 66-581) is not seriously affected by radiation either in air or vacuum to an exposure of 10^9 ergs g^{-1} (C). At 10^{10} ergs g^{-1} (C), the effect of irradiation is about the same whether or not air is present. When tensile strength was determined in a vacuum (dynamic tests, Table A-29), it appeared somewhat lower than when tested in air (static tests). Weight loss was approximately 1 per cent (Table A-31).

Tensile strength and elongation of natural rubber O-rings changed considerably when irradiated in vacuum to 9×10^9 ergs g^{-1} (C). However, up to 5×10^9 ergs g^{-1} (C), there was little difference between irradiation in air and in vacuum. No significant change in weight occurred.

Irradiation to an exposure of 10^9 ergs g^{-1} (C) had practically no effect on neoprene either in air or in vacuum. Dynamic tests (tests in vacuum) showed little difference from the tests in air (see Tables A-28 and A-29).

Radiation effects on Viton-B appeared to be similar whether irradiated in air or in vacuum. Elongation decreased considerably after 10^9 ergs g^{-1} (C) (compare Tables A-28 and A-30).

A nitrile rubber containing an antirad (PRP 737-70) showed better tensile strength when irradiated in air than in vacuum. After 10^9 ergs g^{-1} (C), elongation decreased considerably in air. No comparable data for vacuum were given.

All of these materials except Viton-B showed good stability to radiation both in air and in vacuum to about 10^9 ergs g^{-1} (C), but above that exposure, changes in physical properties were large. Viton-B showed considerable change at 10^9 ergs g^{-1} (C). At the highest exposures, natural and nitrile rubber appeared to be damaged more by exposure to gamma radiation in vacuum than exposure in air. Neoprene and Viton-B were not tested to sufficiently high radiation levels in vacuum to determine the effect of vacuum on gamma-radiation damage.

Wahl and Robinson[35] exposed several elastomeric seals to a gamma exposure of 5×10^6 ergs g^{-1} (C) in a vacuum (2×10^{-6} torr at beginning of exposure and 9×10^{-6} torr at end of exposure) and measured weight and Durometer hardness changes. Samples remained in vacuum condition for 1 week following the radiation exposure before they were tested. No gross physical property changes of the seals were observed. Data are given in Table A-32.

Gray[9] determined the effect of radiation and vacuum exposure on the compressive and tensile strength of Fluorobestos, a mixture of Teflon and random asbestos fibers. The results of these tests, shown in Table A-33, indicate that the material would still remain useful as a gasket material after radiation exposure of 10^9 ergs g^{-1} (C) in vacuum.

Gray, et al.,[8] investigated the performance of seals and gaskets to determine both design and material limitations, particularly those for unlubricated vacuum service. The studies consisted of performance tests and the determination of leak rates in static and dynamic operations. Tests included both rotational and reciprocating motion. Leakage rates were measured by means of a helium leak detector connected to the interior of the seal test container. The vacuum level was maintained below 10^{-6} torr except in cases of seals for which leakage rates were too high to maintain the vacuum.

All seals were dusted with molybdenum disulfide before installation. Elastomers examined for use as seals in reciprocating engines included neoprene, silicone, Viton-A, nitrile (Buna N), and Butyl rubbers. Also tested were Kel-F, polyethylene, and polyvinyl chloride. Materials tested for rotating seals were silicone rubber, Viton-A, Kel-F elastomer, Teflon, and Kel-F. Leakage rates and pertinent comments on wear and abrasion effects are shown in Table A-34 in Appendix A.

Polyethylene and silicone rubber were the most effective seals for reciprocating service. Leak rates were very low, 5×10^{-5} standard cubic centimeters of helium gas, after test durations of 30 minutes. It was found that a dry lubricant such as molybdenum

disulfide improved performance. Silicone rubber and Viton-A proved to be good materials for rotational motion. Again, small amounts of dry lubricants were beneficial. Seal positioning and loading were found to be critical, and have to be carefully designed.

Teflon was particularly ineffective because of its relatively rigid, inflexible properties. The material wore rapidly since it was not as porous as the elastomers and would not accept a surface coating of lubricant such as molybdenum disulfide to reduce friction and wear. Gray points out that self-lubricating properties of a material apparently do not increase its life when operated as a dynamic vacuum seal.

Abrasion and tearing were major problems. Many of the seals were turned and split after a few minutes' operation. Viton-A was an example of this mode of failure.

Static seal tests were conducted on the same elastomers used for the dynamic tests. Seals were loaded to obtain the deflections and contact pressures recommended by the manufacturers. Leak rates were measured before and after operation. Data are given in Table A-34. Some seals such as silicone rubber exhibited a reduced leak rate for static sealing after being subjected to dynamic operation.

Polyethylene and polyvinyl chloride (Vinylite) in an O-ring configuration were very effective in static applications. These materials as well as the remainder of the elastomers tested were not appreciably affected by a 2-week vacuum exposure at 1×10^{-7} torr.

In another study of sealants for space environment, Farkass and Barry[12] screened seven elastomer materials for use as O-ring-type door seals. These were studied from the standpoint of outgassing and leakage rates in a high vacuum environment. Again, a radiation environment was not considered in these studies. Butyl rubber, Viton-A, neoprene, and Buna-N were roughly comparable in combined gas load (leakage plus outgassing) during the screening tests, with preference in the order named. Natural rubber was eliminated because of excessive physical damage, and Teflon was rejected because of permanent deformation. Silicone O-rings were substantially poorer in combined leakage and outgassing, although the outgassing studies rated the silicones as lowest in actual outgassing with Butyl, Viton-A, and neoprene in descending order of merit. The degree of compression of the O-rings was found to be an important factor and the effect of compression was approximately the same for all the materials tested.

The effect of temperature was explored in the range from 25 C to 100 C. Helium leak rate increased, at first, with increase in temperature for all the elastomers studied. However, different elastomers reacted differently to long exposure at 100 C. The leak rate of the silicones ultimately decreased by a hundredfold, but the deformation made it impossible to re-use the O-ring. Butyl rubber is not deformed by prolonged heating and the leak rate remains at the level initially reached. Neoprene and Viton-A performed in a manner intermediate to these two extremes.

Tables 20, 21, and 22 show the air leak rates of the better elastomers at 20 C and at 100 C, as well as the permeability and effect of loading on the air leakage rates.

TABLE 20. AIR LEAK RATE OF ELASTOMER COMPOUNDS[42][a]

Compound	Leak Rate, std cc air/inch/year	
	20 C	100 C
Silicone (Compound 76-128)	2.2	3.6
Silicone (Compound 77-018)	2.1	3.6
Neoprene	0.03	0.29
Viton-A	0.022	0.44
Butyl	<0.001	0.37

(a) Elastomer was loaded by four clamps with 40 foot-pounds torque on each clamp in addition to atmospheric pressure.

TABLE 21. COMPARISON OF REAL AIR LEAK RATES OF ELASTOMERS AS MEASURED EXPERIMENTALLY AND AS CALCULATED FROM PERMEABILITY VALUE[42]

Material	Permeability[a], std cc/(cm^2)(cm)(atm)(sec)	Leak Rate at 100 C, std cc air/inch/year	
		Calculated	Experimental[b]
Viton-A	8.8×10^{-8}	0.36	0.44
Neoprene	7.0×10^{-8}	0.29	0.29
Silicone (Compound 76-128)	450×10^{-8}	18.40	3.60
Silicone (Compound 77-018)	Ditto		
Butyl	3.2×10^{-8}	0.13	0.37

(a) Obtained from WADC Technical Report 56-331, References 20-23, cm^2 refers to thickness of material.
(b) The clamp torque was approximately 40 foot-pounds during these measurements.

TABLE 22. RELATION OF AIR LEAK RATE OF GASKET MATERIAL TO LOADING[42]

Torque on Clamps, ft-lb	Air Leak Rate, std cc air/inch/year			
	Neoprene	Silicone	Butyl[a]	Viton-A
0 (atmospheric pressure)	1.28	10.0	<0.001	1.1
10	0.22	4.0	<0.001	0.2
20	0.09	2.8	<0.001	0.08
30	0.03	2.4	<0.001	0.04
40 (normal operating torque)	0.03	2.2	<0.001	0.022
60	0.03	2.2	<0.001	0.02
80	0.03	2.0	<0.001	0.02
100	0.018	1.6	<0.001	0.01
150	0.002	1.4	<0.001	0.01

(a) It should be pointed out that, in the case of a pressurized container subjected to space environment, the atmospheric pressure would not ordinarily be acting to compress the rubber sealant material. Therefore, the conclusion that an adequate seal can be constructed employing the action of atmospheric pressure on a flanged door using a Butyl O-ring gasket should not be too hastily drawn from these figures.

Thermal Insulation (Foamed Materials)

Polyurethane foamed materials appeared stable when irradiated to 5×10^8 to 1×10^9 ergs g^{-1} (C) in air and in vacuum. At cryogenic temperatures, the approximate threshold point for compressive resistance was an exposure of about 5×10^9 ergs g^{-1} (C). The radiation threshold at cryogenic temperatures for a polystyrene thermal insulation was about 5×10^9 ergs g^{-1} (C).

Two polyurethane foamed materials manufactured by Chemical Plastics Research Company were irradiated in vacuum at General Dynamics and tested for compression strength at 25 per cent deflection in air and in vacuum.(7) After a radiation exposure of 10^9 ergs g^{-1} (C), compression strength of CPR-20 did not change when tested in air (100 psi to 99 psi). When tested in vacuum to a radiation exposure of 5×10^8 ergs g^{-1} (C), compression strength for 25 per cent deflection increased to 124.5 psi. With the second material, CPR-1021-2, compression strength at 25 per cent deflection again did not change significantly when tested in air after being irradiated in vacuum to 5×10^8 ergs g^{-1} (C) gamma exposure. Values were 33 psi and 29.8 psi before and after irradiation, respectively. When tested in vacuum, after the same radiation exposure, compression strength increased to 49.4 psi.

Stayfoam AA 402, also a polyurethane thermal insulation material was irradiated at cryogenic temperatures.(43) There appeared to be an approximate threshold point for compressive resistance of this material at an exposure of about 5×10^9 ergs g^{-1} (C).

Styrofoam 22, a polystyrene thermal insulation, showed a radiation threshold of 2 to 5 x [illegible] ergs g^{-1} (C) at cryogenic temperatures.

ELASTOMERS

Radiation data relative to elastomeric materials since the publication of REIC Report No. 21 have resulted primarily from radiation studies of end items and components of operational equipment. Efforts to develop new and improved materials have met with only limited success, and, as a result, these studies have been cut back. Data on the effect of extreme temperatures and of vacuum with radiation are included in this report. Many of the data have been presented in the discussion of various components, but information of general significance is included under the several types of elastomers. For information on those elastomers for which no additional pertinent data have been received, the reader is referred to REIC Report No. 21, September 1, 1961.

Elastomers are among the most sensitive to environment of any of the materials considered for equipment to be used in space.(44) Vulcanizates containing plasticizers, oils, and other compounding ingredients are more apt to be affected adversely by space environments than are polymers without these additives. However, for applications such as seals or gaskets, there are few other materials which may be used satisfactorily. As a result, work is continuing in such areas to develop satisfactory seal materials.

Polyacrylic Rubber

The radiation stability of acrylic rubbers is slightly inferior to those of nitrile and neoprene rubbers. An exposure of 10^9 ergs g^{-1}(C) will effect an over-all change in physical properties of 25 per cent.

Hycar 4021 exposed to 400 F for 5 days in vacuum retained appreciable strength, although elongation decreased considerably.

No additional radiation-effects data were received since issuance of REIC Report No. 21. However, some information on the effect of vacuum was noted. Hycar 4021 exposed to 400 F for 5 days in vacuum retained appreciable strength, although elongation decreased considerably.(45) Compound formulations and values of the properties tested are given in Tables B-1 and B-2 in Appendix B. These data are included to help in design of parts for space, since, in general, radiation deterioration in air is greater than that in vacuum.

Butyl Rubber

Butyl rubber has probably the least radiation stability of any of the common synthetic rubbers. Twenty-five per cent damage is reached for tensile strength and elongation at about 10^9 ergs g^{-1}(C).

Ultraviolet radiation in vacuum caused an increase in tensile strength of about 10 to 15 per cent. Elongation decreased 10 to 25 per cent.

No additional data on effects of radiation on butyl rubber were received. Data on the effects of vacuum and temperature are given below. DeWitt(9) found Butyl rubbers

K-121 and K-1330 increased in hardness, decreased in elongation, and only slightly changed (7 per cent) in tensile strength when exposed to vacuum (10^{-4} to 10^{-5} torr) and elevated temperature (250 to 300 F).

Snyder[46] exposed Butyl rubber to ultraviolet in vacuum (1×10^{-5} torr) for 24, 96, and 312 hours. In each case, tensile strength increased from about 10 to 15 per cent. Elongation decreased from 10 to 25 per cent. Data are given in Table B-3.

Chlorobutyl, Chlorobutyl-Chloroprene Blends

An attempt was made to achieve a balanced radiation resistance by maintaining a balanced crosslinking/scission reaction. These chlorobutyl-chloroprene blends were a step in this direction, but did not produce the needed improvement.

Chlorobutyl elastomer has, because of its chlorination, additional crosslinking sites. It was felt that gamma radiation could cause crosslinking at these sites and counteract the chain/scission reactions of regular Butyl compounds. For this study Heitz and coworkers[47] selected polychloroprene as the blending elastomer because of its widespread use as a seal material. Results are given in Tables B-4 through B-7 in Appendix B.

After an initial stiffening period, the scission reaction became predominant in the chlorobutyl compound (suggesting a threshold exposure of about 10^9 ergs g^{-1}(C) for scission similar to the one for crosslinking in other polymers). The scission effect seemed to be more predominant in air than in vacuum. The specimen surfaces decomposed to a sticky-tacky condition. Combined radiation prevented the formation of this tacky surface, but that this was purely a surface condition was indicated by a study of the other physical properties.

Increasing the polychloroprene content of the blends increased the tendency for crosslinking as indicated particularly by modulus changes and the lack of surface decomposition except in spots on the clamped ends, and the compound (158-62) containing 75 parts chloroprene to 25 parts chlorobutyl exhibited no surface decomposition at all.

The heat encountered, coupled with the ultraviolet radiation, makes the discussion of combined radiation difficult, but it was felt that blending compounds might be a good way to achieve a balanced radiation resistance, by maintaining a balanced crosslinking/scission reaction without adversely affecting the vacuum stability.

Chlorosulfonated Polyethylene (Hypalon)

Hypalon 30 showed good stress-strain properties up to a radiation exposure of 3.1×10^9 ergs g^{-1}(C).

The addition of 3.3 parts hydroquinone improved the radiation resistance of a base compound. Also, aromatic plasticizers such as Kenflex A improve stability.

In general, the effect of gamma radiation in vacuum is more severe than that of radiation in air.

Hypalon 30 as tested by Wattier, Newell, and Morgan[48] showed good stress-strain properties up to an exposure of 3.1×10^9 ergs g^{-1}(C), after which all properties tested except ultimate strength underwent considerable change. Data are given in Table 23.

TABLE 23. ENGINEERING PROPERTIES[a] OF HYPALON 30 ELASTOMER VERSUS RADIATION[48]

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev)[b] Gamma Exposure (G) ergs g^{-1}(C)[b]	Modulus at 100% Elongation, psi	Ultimate Strength, psi	Ultimate Elongation, %	Compression Set, %	Slope of Load – Deflection Curve, lb/in.
Control	1184/8.7/5	2769/3.4/5	212/8.1/5	32.7/7.3/3	2947/2.4/3
N 2.3×10^{13} G 5.1×10^{7}	1392/5.4/5	2945/2.8/4	208/4.7/4		
N 1.4×10^{14} G 1.8×10^{8}				35.2/4.4/3	3293/3.6/3
N 8×10^{14} G 8×10^{8}				45.2/3.7/4	[illegible]/3.8/4
N 1.2×10^{15} G 3.1×10^{9}	1610/3.2/4	2688/7.3/4	175/ /4		
N 5.5 to 7.0×10^{15} G 1.1 to 1.4×10^{10}		2864/8.8/5	88/12 /5	83.2/6.3/2	7680/3.7/2

(a) Data are given as $\overline{x}$/S.D./n, where $\overline{x}$ = average value, S.D. = standard deviation of an individual observation estimated from the range, and n = number of specimens used in calculating $\overline{x}$ and S.D.

(b) Ambient radiation temperature; test temperature 80 F.

The effects of filler level, antirad, and curing time on the radiation resistance of chlorosulfonated polyethylenes were examined by Heitz.[47] Addition of 3.3 parts hydroquinone (13 -62) improved radiation resistance of the base compound (130-62). Decreased cure time of this formulation produced a compound (13[illegible]-62) with a lower radiation resistance rating (i.e., greater property changes) than the control compound. (See Appendix B, Tables B-8 through B-13.) Increasing the carbon black content (132-62) lowered the rating, but a test of this compound after addition of an antirad (138-62) indicated an improvement.

It was noted the antirad compound cured for 120 minutes and the compounds with the higher level of carbon black showed an initial decrease in modulus, indicating a possible threshold exposure for crosslinking to become predominant. This "threshold" effect was masked by further curing of the material. In any event, crosslinking was increased as the exposure time was increased.

In general, the effect of straight gamma radiation in vacuum was more severe than that of radiation in air. The changes produced by the addition of ultraviolet radiation were mixed insofar as physical-property changes were concerned. The specimen showed a marked increase in weight gain during air irradiation as opposed to vacuum irradiation, indicating a strong oxidation reaction. The mixed radiation increased the weight gain in the vacuum condition and decreased the gains in air.

It must be noted that it was impossible to separate the effects of heat aging from the desired effects of the ultraviolet radiation, and the evaluation of the mixed gamma-ultraviolet radiation effects is colored by this fact.

Fluorocarbon Rubbers

Viton-A reaches threshold damage in air at a gamma exposure of 5×10^8 ergs g^{-1}(C), and 25 per cent damage at 6×10^9 ergs g^{-1}(C). This rubber possesses poor radiation stability when irradiated in air at temperatures higher than about 250 F. However, it can be used at 400 F when irradiated to an exposure of 10^9 ergs g^{-1}(C) in jet turbine oil.

In vacuum there was no significant change in tensile strength at an exposure of 10^{10} ergs g^{-1}(C) at room temperature.

Viton-B irradiated in bis-phenoxy-phenyl ether at 400 F at an exposure of 10^{10} ergs [illegible] showed excellent retention of tensile strength but a decrease of 5[illegible] per cent in elongation.

Kel-F is damaged by 25 per cent at 6×10^8 ergs g^{-1}(C) in air. It is stable in silicate ester fluids at room temperature to 10^{10} ergs g^{-1}(C).

Fluorobutyl acrylate elastomer increases about 40 per cent in tensile strength and 20 per cent in hardness but decreases in elongation by 70 per cent when irradiated in air to an exposure of 10^{10} ergs g^{-1}(C).

According to Kerlin[6] there were wide variations in physical properties of control samples of Viton-A. However, it would appear that, at gamma exposures of 1.6×10^{10} ergs g^{-1}(C) in vacuum, there was no significant change in tensile strength. On the other hand, when Viton-A was irradiated in air, there was an increase in tensile strength of 39 per cent. Vacuum did not appear to make a difference in the change in elongation due to radiation exposure. Weight loss was 1.2 per cent with a vacuum-nuclear radiation exposure of 1.6×10^{10} ergs g^{-1}(C). DeWitt, et al.,[11] found that a vacuum of 5.5×10^{-4} torr and a temperature of 400 F for 6-1/2 hours caused only a slight decrease in tensile strength and elongation of Viton-A and practically no change in hardness. (See Tables B-14 and B-15, Appendix B.)

Podlaseck and Suhorsky[4] measured the change in permeability of Viton-A after exposures to vacuum and ultraviolet for periods of up to 2 weeks. The results (Figure B-1) showed that there were no significant changes. Equilibrium weight loss at 177 C for Viton-A was given by Podlaseck as 20 grams/sq cm/sec $\times 10^{10}$ for a pressure of 10^{-5} torr.

Ossefort and Ruby[45] found that a Viton-B vulcanizate showed better properties when subjected to 600 F in vacuum for 5 days than when exposed to the same temperature in air. However, tensile strength had decreased from 2610 psi to 620 psi. At 5?0 F, tensile strength had decreased only to 2140 psi. Data are given in Table B-16.

Heitz and coworkers[47] studied the effect of the amount and type of filler with Viton-A. They found that increasing the amount of carbon black increased the amount of change induced in the physical properties by exposure to irradiation. The compound containing GPF (152-62) rated slightly lower than the compound containing MT black (151-62), but the pattern of difference was not consistent between them.

Examination of the data in Tables B-17 through B-20 shows that crosslinking, as evidenced by increases in modulus and hardness and decreases in ultimate elongation, started immediately and continued increasing as the exposure time increased.

Radiation in air produced greater changes than radiation in vacuum for all compounds. At low carbon black levels, the combined gamma-ultraviolet radiation produced greater changes than did straight gamma radiation, but the situation was reversed for the higher-carbon-black-content compounds.

The heat effects present in the combined gamma-ultraviolet radiation conditions again made evaluation of the effects of ultraviolet irradiation difficult. However, the heat resistance of the fluoroelastomers provided some help in separating the heat and ultraviolet effects, by minimizing the effects of heat on the elastomers.

Nitrile Rubber

Further work is needed to confirm reported results on the effect of radiation in vacuum because of conflicting data. For example, nitrile rubber appears to be less radiation stable in vacuum than in air. In air at 10^{10} ergs $g^{-1}(C)$ exposure, tensile strength increased from 2459 psi to 3512 psi. In vacuum, tensile strength at 10^9 ergs $g^{-1}(C)$ decreased from 2630 psi to 203 psi.

On the other hand, some nitrile rubber O-rings were not seriously affected by radiation either in air or in vacuum to an exposure of 10^9 ergs $g^{-1}(C)$. At 10^{10} ergs $g^{-1}(C)$, the effect of radiation was about the same whether or not air was present. When tensile strength was determined in a vacuum after irradiation, it appeared somewhat lower than when tested in air after being irradiated in a vacuum.

Additional work on nitrile rubber has included studies of the effects of vacuum, and nuclear radiation and vacuum, and some additional work on the effects of antirads. The latter is discussed in the section on antirads.

Bonanni[49] irradiated Buna N rubber to an exposure of 7.9×10^7 ergs $g^{-1}(C)$ in air, in a closed atmosphere, and in vacuum (5×10^{-5} torr). The per cent change in weight was negligible in each case. In an ampule containing approximately 7 cubic centimeters of air sealed under atmospheric conditions, the degradation of Buna N as a result of gamma irradiation was more severe than that in an open atmospheric condition. The average tensile strength was lower at an exposure of 7.2×10^8 ergs $g^{-1}(C)$, and at 7.9×10^9 ergs $g^{-1}(C)$ tensile strength was about two-thirds that of the samples exposed to gamma irradiation in an open atmosphere. In a vacuum, Buna N lost more

than 50 per cent of its tensile strength after exposure to 7.9×10^9 ergs $g^{-1}(C)$. The per cent elongation followed a straight-line degradation, but with a lower per cent elongation value in vacuum than in air. The value in a closed atmosphere was again intermediate. Thus, nitrile rubber appeared to be less satisfactory when irradiated in a vacuum than when irradiated in air. Data are shown in Figures 12 and 13.

Kerlin[6] found that air produced a harder and more brittle material with Buna N (RA 30760), while vacuum irradiation produced a weak, tacky, ductile material. After exposure to 10^{10} ergs $g^{-1}(C)$ in air, tensile strength increased from 2459 psi to 3512 psi, while after exposure to 10^9 ergs $g^{-1}(C)$ in vacuum, tensile strength decreased from 2630 psi to 203 psi. Data are shown in Tables B-21 and B-22 in Appendix B. No weight loss occurred at a vacuum-gamma radiation dose of 7×10^9 ergs $g^{-1}(C)$. (See also discussion on nitrile rubber under seals, O-rings, and gaskets.)

DeWitt, et al.,[9] studied the effect of vacuum (1.2×10^{-3} torr) and temperature (300 F) on several nitrile elastomers. He found that vacuum exposure increased hardness and decreased elongation, but that tensile data were widely scattered and inconclusive.

Ossefort and Ruby[45] exposed plasticized and unplasticized nitrile rubber compounds to vacuum and elevated temperatures. Properties were not seriously affected after 5 days' exposure at 300 F in vacuum. Data are given in Table B-23.

Polychloroprene (Neoprene)

Tensile strength of neoprene varies depending on the type of polymer, cure, and additives, but in general, tensile strength decreases to a radiation exposure of 4.3 to 8.7×10^9 ergs $g^{-1}(C)$ and then increases with increasing radiation. Twenty-five per cent change occurs at about 10^9 to 5×10^9 ergs $g^{-1}(C)$. Elongation decreases with increased radiation exposure; while hardness does not change to an absorbed radiation of 4.5×10^9 ergs $g^{-1}(C)$.

Reports on the effect of vacuum and radiation on neoprene are conflicting. Some tests have shown improvement in properties in vacuum and others have shown less radiation resistance in vacuum for neoprene. No doubt, the type of neoprene, the filler, compounding materials, and cure affect the stability of the rubber in vacuum.

Data obtained on the effects of radiation on neoprene rubber in vacuum as compared with radiation in air are conflicting. Kerlin[6] irradiated a neoprene rubber (type not specified) in vacuum and in air and the data show the rubber to be very sensitive to vacuum-gamma radiation. At an exposure of approximately 1.9×10^9 ergs $g^{-1}(C)$, tensile strength for the vacuum-irradiated samples decreased from 3134 psi to 191 psi; in air the decrease was from 3297 to 2769 psi. The decrease in elongation was of the same order of magnitude in both cases. Weight loss was not considered significant. Data are shown in Tables B-24 and B-25 in Appendix B.

On the other hand, Bonanni[49] irradiated a neoprene rubber to 7.9×10^9 ergs $g^{-1}(C)$ and found little difference between the effect of radiation in vacuum, in air, and in a sealed atmospheric environment. Data are shown graphically in Figures 14 and 15. Heitz, et al.,[47] found that room-temperature irradiation in air generally produced somewhat greater changes than room temperature irradiation in vacuum, although the

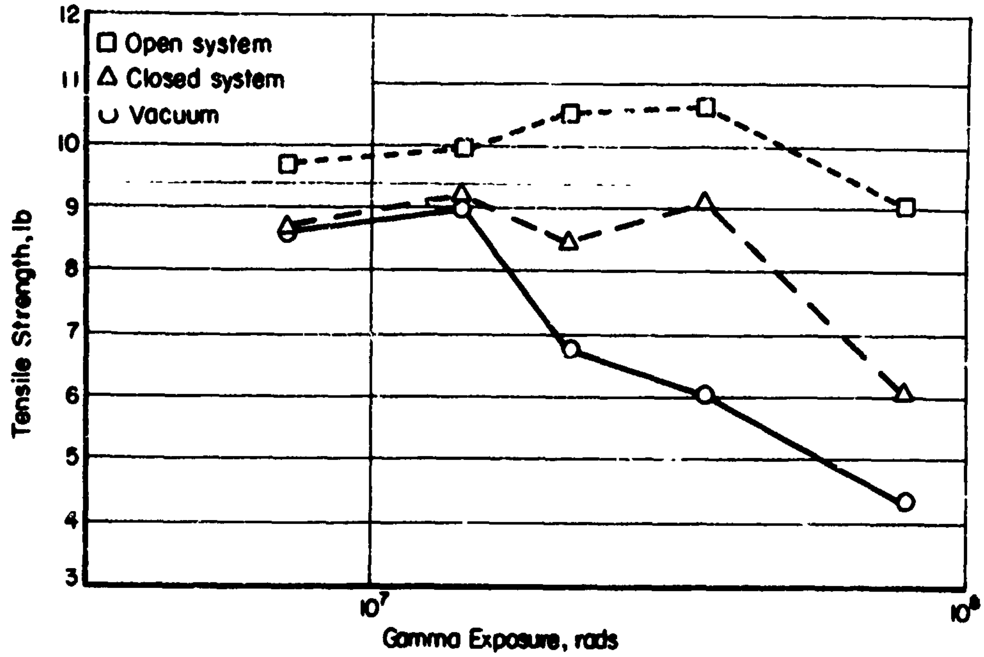


FIGURE 12. TENSILE STRENGTH VERSUS GAMMA EXPOSURE (Buna N)(49)

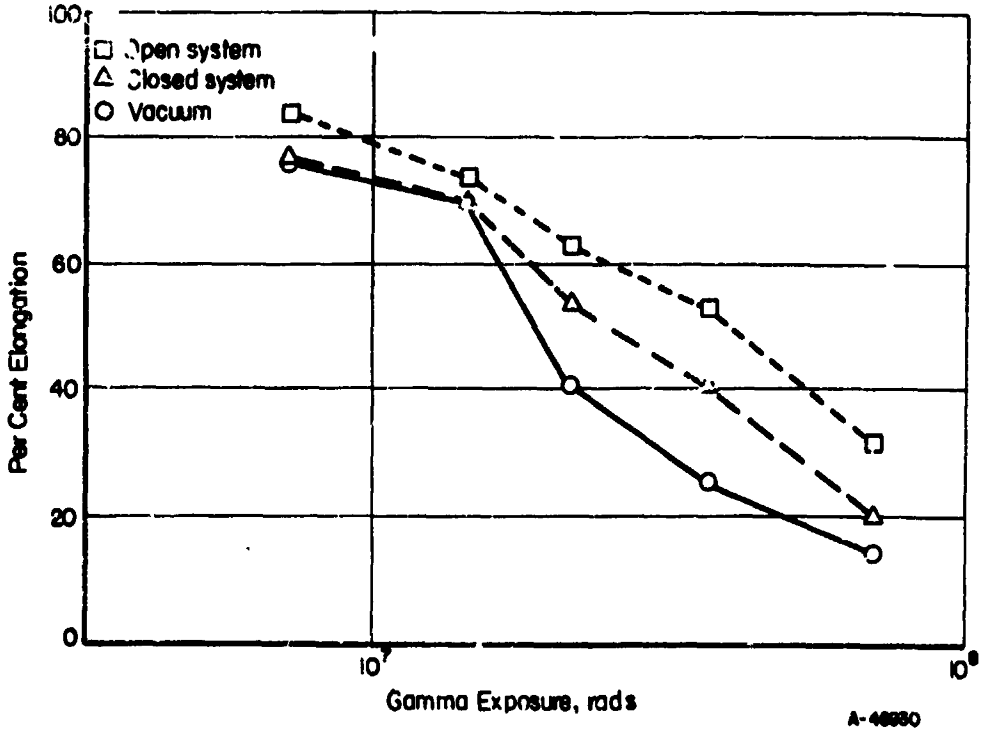


FIGURE 13. PER CENT ELONGATION VERSUS GAMMA EXPOSURE (Buna N)(49)

9)

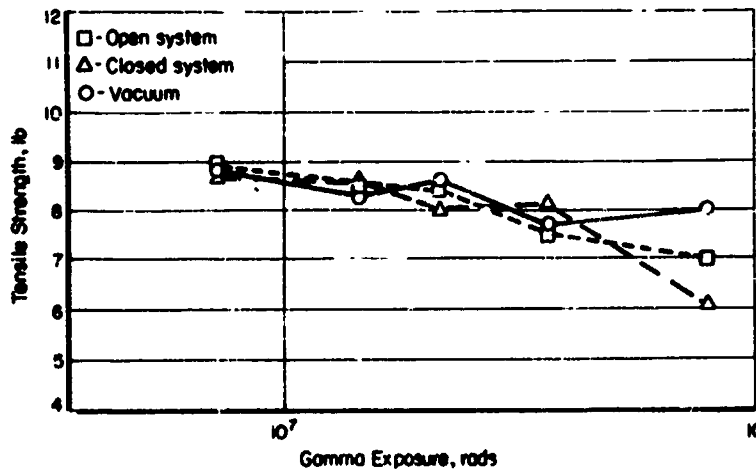


FIGURE 14. TENSILE STRENGTH VERSUS GAMMA EXPOSURE (Neoprene)(49)

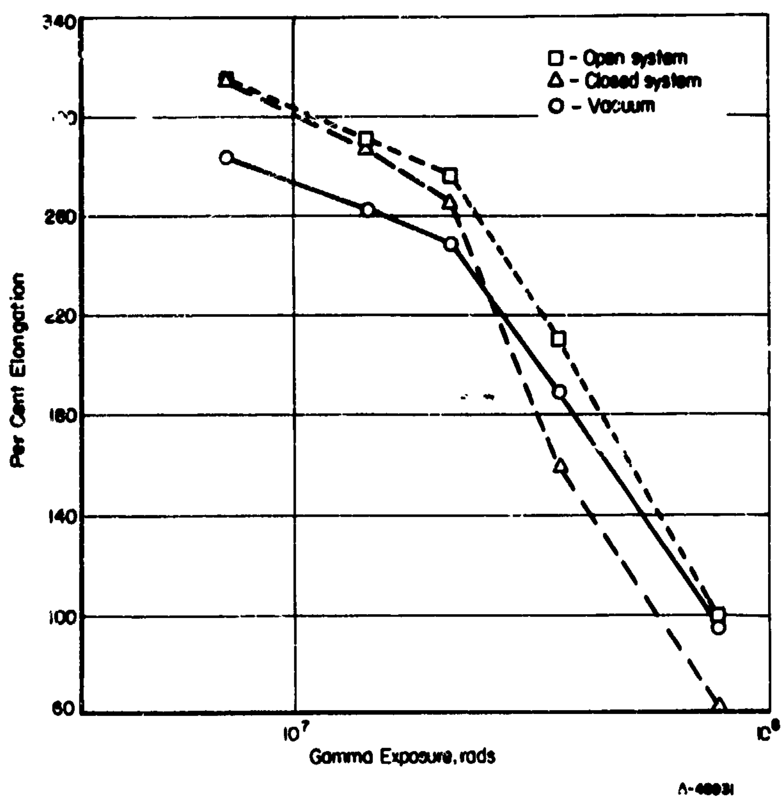


FIGURE 15. PER CENT ELONGATION VERSUS GAMMA EXPOSURE (Neoprene)(49)

differences were in general not large. There was one exception in which Neoprene WRT having 35 parts of SRF carbon black showed a much greater change in tensile strength in air than in vacuum (see Table 24).

TABLE 24. EFFECT OF GAMMA RADIATION AND VACUUM ON NEOPRENE WRT COMPOUNDS AT ROOM TEMPERATURE(47)

Compound	Description	Radiation Exposure, ergs g^{-1}(C)	Tensile Strength, psi Irradiated in Air	Tensile Strength, psi Irradiated in Vacuum	Elongation, per cent Irradiated in Air	Elongation, per cent Irradiated in Vacuum
138-62	35 parts SRF carbon black	None	2303		537	
		3.6×10^9	579		23	
		4.3×10^9		2140		77
139-62	35 parts SRF carbon black, 2 % hydroquinone	None	2149		516	
		3.6×10^9	1016		70	
		4.3×10^9		1367		123
140-62	35 parts SRF carbon black, 5 % hydroquinone	None	1835		517	
		3.6×10^9	1063		93	
		4.3×10^9		1243		123
159-62	50 parts HAF carbon black; cured 40 min at 293 F	None	2654		287	
		3.6×10^9	898		27	
		--		--		--
161-62	50 parts HAF carbon black; cured 20 min at 293 F	None	1651		437	
		4.3×10^9	2116		53	
		4.3×10^9		1864		47

The reasons for the conflicting data are not known, but could be due to the types of neoprene studied, differences in compounding, and cure. No definite conclusions on the relative effect of radiation in vacuum and radiation in air can be made at this time.

Wattier, Newell, and Morgan(48) studied postirradiation effects on three neoprene elastomers. They reported tensile data for specimens irradiated at 75 F and stored at 75 F and at -20 F for 1, 4, 11, and 29 days before testing. Data are given in Tables 25 and 26. Postirradiation changes were noted in two of the three neoprenes. In the Kirkhill and Rubbercraft neoprenes (60 mils thick), a postirradiation decrease in tensile strength with time occurred with room-temperature storage. There were no detectable postirradiation effects in the special O-ring formulation of neoprene (78 mils thick) by Parco. When neoprene is stored in an oxidizing atmosphere, postirradiation changes probably will be more noticeable in thin samples than in thick ones due to the time for diffusion of the oxygen through the rubber.

TABLE 25. TENSILE PROPERTIES(a) OF NEOPRENE RUBBERS AND BUNA-N VERSUS POSTIRRADIATION STORAGE TIME(48)

Integrated Neutron Flux (N), n cm^{-2} (E > 2.9 Mev)(b) Gamma Exposure (G), ergs g^{-1}(C)(b)	Days Tested After Irradiation	Neoprene Rubber (Kirkhill)(b): Miniature, 60 Mil Thick, 75 F(c) Ultimate, psi	Neoprene Rubber (Kirkhill)(b): ASTM, 60 Mil Thick, -20 F(c) Ultimate, psi	Neoprene Rubber (Kirkhill)(b): ASTM, 60 Mil Thick, 75 F(c) Ultimate, psi	Neoprene Rubber (Rubbercraft)(b): Miniature, 60-Mil Thick, 75 F(c) Ultimate, psi	Neoprene Rubber (Rubbercraft)(b): Miniature, 120-Mil Thick, 75 F(c) Ultimate, psi	Neoprene Rubber (Rubbercraft)(b): ASTM, 60-Mil Thick, 75 F(c) Ultimate, psi	Neoprene Rubber (Rubbercraft)(b): ASTM, 120-Mil Thick, 75 F(c) Ultimate, psi
Control	1	1830/2.3/8	1805/4.9/9	1780/4.6/12	2940/5.4/9	1850/5 /9	2210/2.8/12	1980/2.6/9
N 1.5×10^{15} G 7×10^{9}	1	1405/4.9/5		1350/8.3/5	1600/11 /5	1420/12 /5	1430/9.9/4	1350/11 /5
N 2.5×10^{15} G 1×10^{10}	1	1725/14 /4		1670/12 /4	1585/8.6/4	1505/7.4/4	1354/13 /5	1320/6.9/5
N 5×10^{15} G 2×10^{10}	1	3355/12 /4	3654/4.2/5	4030/5.1/4	2925/13 /4	2610/6.3/4	3460/5.1/4	2620/3.6/3
	5	3650/5.2/4	3858/9.1/5	3760/8.3/4	3058/12 /4	2520/3.3/5	3060/12 /4	2654/5.7/5
	9	3145/11 /4	3760/5.3/5	3440/10 /5	2344/9.7/5	2515/17 /4	2820/2.6/4	2060/3.4/5
	35	2930/5.8/4	3675/8.3/5	3085/4.6/4	2640/9.3/5	1590/17 /4	2515/3.3/4	2750/7.2/4

		Neoprene Rubber (Kirkhill)(b): Miniature, 60 Mil Thick, 75 F(c) Ultimate psi	Neoprene Rubber (Kirkhill)(b): Miniature, 60 Mil Thick, 75 F(c) Ultimate Elongation, %	Neoprene Rubber (Kirkhill)(b): ASTM, 60 Mil Thick, 75 F(c) Ultimate, psi	Neoprene Rubber (Kirkhill)(b): ASTM, 60 Mil Thick, 75 F(c) Ultimate Elongation, %	Buna-N Rubber(b): Miniature, 60 Mil Thick, 75 F(c) Ultimate, psi	Buna-N Rubber(b): Miniature, 60 Mil Thick, 75 F(c) Ultimate Elongation, %	Buna-N Rubber(b): ASTM, 61 Mil Thick, 75 F(c) Ultimate, psi	Buna-N Rubber(b): ASTM, 61 Mil Thick, 75 F(c) Ultimate Elongation, %
Control	1	1961/4.8/10	267/9.5/10	1838/6.5/8	242/6.1/7	1552(d)	262(d)	1307(d)	223(d)
	4	1356/2.2/10	268/3.1/10	1820/2.1/9	[illegible]/2.1/9				
	11	1903/5.6/10	277/7.9/9	1845/1.3/9	249/1.5/7				
	29	1957/2.9/10	245/2.9/8	1870/1.3/8	247/2.2/8				
N 1×10^{15} G 8.7×10^{9}	1	2280/11 /6	9/35 /6	4800/6 /7	5.5/6.7/7	40[illegible]0/	17/	3430/	18/
	4	2090/7.8/9	10/4.2/8	4016/5.4/10	5.6/12 /10	4360/	17/	3350/	19/
	11	1966/22 /9	14/19 /9	3040/8.2/9	7.6/18 /9	4861/	16/	3480/	20/
	29	1550/14 /[illegible]	13/19 /8	2826/7 /[illegible]	[illegible]/ /10	4752/	15/	3280/	20/

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of an individual observation estimated from the range, and n = number of samples used in calculating $\bar{x}$ and S.D.

(b) Radiation temperature and test temperature, 75 F.

(c) Storage temperature.

(d) Individual values not available; average obtained from 4 to 8 samples.

(b) Radiation temperature and test temperature, 75 F.
(c) Storage temperature.
(d) Individual values not available; average obtained from 4 to 8 samples.

TABLE 26. TENSILE PROPERTIES[a] OF NEOPRENE VERSUS POSTIRRADIATION STORAGE TIME[48]

Integrated Neutron Flux (N), n cm^{-2} (E > 2.9 Mev)[b] Gamma Exposure (G), ergs g^{-1}(C)[b]	Days Tested After Irradiation	Neoprene (Parco 3046-60)[b]				
		Modulus, psi			Tensile Strength, psi	Ultimate Elongation, %
		At 25% Elongation	At 50% Elongation	At 100% Elongation		
Control	1	141/16 /5	262/8.7/5	539/17 /5	2375/4.8/5	334/2.7/5
	3	151/8.1/7	254/7.7/7	545/8.9/7	2058/5.2/7	324/8.7/7
	10	170/15 /10	277/17 /10	532/17 /10	2005/6.7/10	321/10 /10
	34	154/11 /9	265/9.9/9	511/8.7/9	2223/4.5/9	330/4 /9
N 1.9×10^{15} G 1.2×10^{10}	1	920/32 /5	2066/30 /5		2150/18 /5	56/13 /5
	3	826/38 /5	1818/5 /5		2071/15 /5	52/17 /5
	10	664/20 /5	1872/20 /5		2291/8.9/5	55/20 /5
	34	785/6 /5	1820/25 /5		1926/24 /5	51/4.8/5

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of an individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Irradiation, storage, and test temperature, 75 F.

Heitz[47] studied the effect of cure, antirad (hydroquinone), and carbon-black type and level on neoprene. Addition of 2.0 parts of the antirad (Formulation 139-62, see Tables B-26 through B-31) decreased the radiation-induced physical changes in air by about 20 per cent, and an increase in the level of 5.0 parts decreased the changes by about 30 per cent. However, changing from 35 parts of SRF black to 50 parts HAF black (159-62) decreased the changes to a greater extent.

In general, the reaction was predominantly crosslinking and the crosslinking increased markedly with increases in dosage. Room-temperature irradiation in air generally produced greater changes than room-temperature radiation in vacuum, but the situation was generally reversed in the combined nuclear radiation-ultraviolet radiation exposures. The specimens seemed to gain weight during exposure, particularly after air exposure, and this increase was even more marked by the addition of ultraviolet irradiation and heat.

Snyder[46] exposed neoprene to ultraviolet radiation in vacuum. Exposure was at 80 and 155 F for 24, 96, and 312 hours. Ultraviolet caused tensile strength to increase and elongation to decrease. Values are given in Table B-32.

Data have also been reported for the effect of vacuum and elevated temperatures without exposure to radiation. DeWitt[9] found that vacuum exposure of 5×10^{-4} torr and a temperature of 300 F for 3 hours caused an increase in tensile strength and hardness and a decrease in elongation (see Table B-15).

Ossefort and Ruby[45] showed the effect of exposure to elevated temperatures and vacuum. Data are given in Table B-33. Both plasticized and unplasticized materials were tested. Samples were oven-aged for the same temperature exposures for comparison. In general, properties did not change significantly up to 212 F. At 300 F, and 5-day exposure, tensile strength decreased by approximately 25 per cent. However, properties had not changed to such an extent as to affect serviceability for most applications.

Styrene-Butadiene (SBR)

Styrene-butadiene rubber (SBR) commonly called GR-S resists radiation better than most of the common synthetic rubbers, but is not equal to natural rubber in radiation resistance. Threshold damage is reached at 2×10^8 ergs g^{-1}(C), and 25 per cent damage is accrued at 1×10^9 ergs g^{-1}(C).

No data on the effect of radiation and vacuum were reported. At elevated temperatures, tensile strength is better in vacuum (no radiation) than in air.

Data on radiation effects on SBR rubber included the effects of some antirads and are discussed in the section on antirads. Ossefort and Ruby[45] examined the effect of vacuum and elevated temperature on SBR vulcanizates with and without an antiozonant. Specimens with antiozonant lost their ozone resistance after exposure to vacuum at either room or elevated temperature. The antiozonant no doubt sublimed under vacuum and so was removed from the vulcanizate. Data are given in Table B-34, Appendix B.

Polysulfides

Polysulfide rubbers have poor radiation stability. An exposure of 10^8 ergs g^{-1}(C) in air is sufficient to damage Thiokol ST seriously. However, it retains its elongation to a greater extent than do most elastomers. After an exposure of 10^{10} ergs g^{-1}(C), both Thiokol ST and FA retained considerable elongation. Thiokol materials can be used for applications where flexibility is required without any great strength.

Differences in the effects of radiation in air and in vacuum are not marked.

Heitz, et al.,[47] studied the effect of gamma radiation, vacuum, and ultraviolet on polysulfide elastomers. These were vendor compounded, and the only known variation was the type of curing agent. One dichromate-cured compound (154-62), one lead peroxide-cured compound (155-62), and two manganese dioxide-cured compounds (146-62 and 167-62) were tested. Data are given in Appendix B, Tables B-35 through B-39.

The main observable difference between the curing agents was in the inferior heat resistance of the lead peroxide-cured compound (155-62) compared with that of the other three, although all compounds were affected by heat.

The primary reaction when irradiated was chain scission, and this grew more marked as the exposure was increased. In the case of the lead peroxide and manganese dioxide cures, this was indicated by decreases in modulus and hardness. The dichromate cure, however, produced slight increases in modulus along with slight decrease in hardness, indicating a possibility of a more balanced crosslinking/chain scission reaction.

The atmosphere effect (i.e., radiation in air versus vacuum) did not appear to be marked. Evaluation of the effects of ultraviolet irradiation was rendered impossible by the heat which accompanied the radiation and the heat sensitivity of the compounds.

Wattier, Newell, and Morgan[48] examined Thiokol ST rubber for postirradiation effects. There was evidence for some recovery of tensile strength. Materials tested for 1, 3, 10, and 34 days after being irradiated to 1.1×10^{10} ergs g^{-1}(C) increased in tensile strength (see Table B-40).

Polyurethane Rubber

Polyurethane rubber is one of the more radiation-resistant elastomers. It is damaged by 25 per cent at an exposure of about 4×10^9 ergs g^{-1}(C). Hardness is unaffected even at 8.7×10^{10} ergs g^{-1}(C).

Irradiation in vacuum has about the same effect as irradiation in air. The effects of combined radiation and temperature up to 260 F are approximately the same as for radiation alone with respect to tensile strength. Elongation is greater at the elevated temperatures.

Cure and filler are important considerations in determining radiation stability of polyurethane rubbers.

Polyurethane rubber is recognized as being one of the more radiation-resistant elastomers. Born and associates[41] found Estane VC cured with 4 phr DiCup (dicumyl peroxide) to be the most radiation-resistant compound tested. It required an exposure of 5.5×10^9 ergs g^{-1}(C) to induce 50 per cent net compression set. On the other hand, Adiprene C, a carbon-black-reinforced sulfur-cured polyurethane, showed poor radiation resistance. Thus cure and filler are important considerations in determining radiation stability. Born indicated that the type of crosslink appeared to play an important role in the radiation resistance of the different polyurethanes. Also, spatial arrangements of the polymer chains, the degree of aromaticity, and the polymer main-chain composition were important factors in the radiation resistance of the polyurethane.

Effects of Temperature and Radiation

Wattier, Newell, and Morgan[48] irradiated fifteen commercial polyurethane elastomers and studied the effect of postirradiation storage time on some of these and the effect of elevated temperature on others. In general, their findings substantiated the fact that polyurethane rubbers are among the most radiation resistant of the elastomers. Ultimate tensile strength and elongation of all the elastomers decreased at the highest radiation doses. No major postirradiation effects are evident in their data and for most of the elastomers a temperature of 260 F did not seriously affect tensile strength of either the irradiated or nonirradiated samples. Elongation was greater for the samples irradiated at 260 F than for those irradiated at 80 F. In both cases, the test temperature was at 80 F. A summary of the polyurethanes studied and the results of radiation are shown in Table 27. Data for the individual elastomers are given in Tables B-41 through B-50 in Appendix B.

Seilon [illegible] R-80T, a polyurethane elastomer produced by Seiberling Rubber Co., was irradiated at [illegible] F and at 250 F to a gamma exposure of 9.4×10^{10} ergs g^{-1}(C) at the lower temperature and 8×10^{10} ergs g^{-1}(C) at the higher temperature.[15] Preliminary observations indicate that this elastomer has excellent radiation resistance. However, the original hardness of the materials before irradiation was about 96, Shore A, which is higher than is desirable for most applications. Data are given in Table 28.

A flexible polyurethane foam, a blown polyether urethane produced by General Foam Co., was also irradiated at 75 F and 250 F. Data are given in Table 29. It can be seen that at the lower temperature, compression set at 50 per cent deflection increased from 8 per cent to 20 per cent at 10^9 ergs g^{-1}(C), to 95 per cent at 8.3×10^9 ergs g^{-1}(C), and 100 per cent at 2.8×10^{10} ergs g^{-1}(C). At the highest dose, 9.4×10^{10} ergs g^{-1}(C), the material adhered to the plates. At 250 F, compression set of the unirradiated material was 103 per cent and irradiation did not change this value. However, at an exposure of 8×10^{10} ergs g^{-1}(C), shrinkage and sticking to the plates again was encountered.

Effects of Radiation and Vacuum

Golden and Hazell[50] determined the effect of high energy radiation in air and in vacuum on polyurethane rubber. He found that tensile strength and elongation were steadily reduced by electron radiation. The effect is more marked in vacuum than in air. In vacuum, complete loss of strength of Vulkollan Grade 2018/40 (hardness 60 ± 5) was caused by an exposure of 10^{10} ergs g^{-1}(C).

TABLE 27. EFFECT OF RADIATION AND TEMPERATURE ON POLYURETHANE ELASTOMERS

Polyurethane	Temperature of Irradiation, F	Exposure Dose[a], ergs g^{-1}(C)	Test Temperature, F	Tensile Strength, psi	Elongation, per cent
Genthane S	75	None	75	2360	468
(General Tire)	75	3.7×10^{10}	75	386	63
3109-B-13	75	None	75	4745	434
(Du Pont)	75	2.1×10^{10}	75	3325	128
Disogrin 1-DSA-	75	None	75	7222	666
6865	75	2.2×10^{10}	75	899	56
Disogrin 1-DSA-	75	None	75	4688	583
4250	75	2.2×10^{10}	75	2574	77
Adiprene L (Du	80	None	80	5346	390
Pont) 12 Phr		7×10^{10}	80	1679	75
MOCA Cure:	260	None	80	5542	420
3 hr at 100 C		5.4×10^{9}	80	1513	299
Adiprene L-167	80	None	80	5949	328
18 Phr MOCA		7×10^{10}	80	2650	63
Cure: 1 hr at	260	None	80	6013	358
100 C		5.4×10^{9}	80	3111	326
Adiprene L-167	80	None	80	1002	452
5.8 Phr 1,4		7×10^{10}	80	604	69
Butanediol	260	None	80	1361	499
1 Phr		5.4×10^{9}	80	575	465
Trimethylprop					
Cure: 4 hr at					
140 C					
Genthane S-1	80	None	80	5564	589
		7×10^{10}	80	906	26
	260	None	80	5697	614
		1.9×10^{10}	80	1218	138
Genthane S-2	80	None	80	2932	598
		7×10^{10}	80	692	25
	260	None	80	3008	622
		1.9×10^{10}	80	888	165
General Tire	80	None	80	4102	596
Type R		7×10^{10}	80	890	29
	260	None	80	4160	609
		1.9×10^{10}	80	992	139

TABLE 27. (Continued)

Polyurethane	Temperature of Irradiation, F	Exposure Dose[a], ergs g^{-1}(C)	Test Temperature, F	Tensile Strength, psi	Elongation, per cent
Disogrin 1-DSA-6365	80	None	80	4989	685
		7×10^{10}	80	830	36
	260	None	80	4345	676
		1.9×10^{10}	80	1260	278
Disogrin 1-DSA-7560	80	None	80	5254	718
		7×10^{10}	80	850	35
	260	None	80	--	--
		1.9×10^{10}	80	1474	362
Disogrin 1-DSA-9250	80	None	80	5544	578
		7×10^{10}	80	2426	27
	260	None	80	4585	566
		1.9×10^{10}	80	2285	247
Disogrin 2-DSA-8445	80	None	80	(5418)[b]	645
		7×10^{10}	80	1050	47
	260	None	80	5082	555
		1.9×10^{10}	80	--	--
Disogrin 2-DSA-9840	80	None	80	5661	563
		7×10^{10}	80	2585	56
	260	None	80	5917	599
		1.9×10^{10}	80	2524	330
Disogrin 3-DSA-8050	80	None	80	(5759)[b]	(588)[b]
		7×10^{10}	80	1075	44
	260	None	80	--	--
		1.9×10^{10}	80	--	--
Disogrin 3-DSA-9045	80	None	80	3407	598
		7×10^{10}	80	2472	49
	260	None	80	2928	616
		1.9×10^{10}	80	2071	313

(a) Control specimens were subjected to the same nonnuclear environment and test procedures as the irradiated ones.

(b) Numbers in parentheses are values from equivalent test.

TABLE 28. SUMMARY OF EFFECTS OF IRRADIATION AT TWO TEMPERATURES ON SEILON UR-80T (POLYURETHANE ELASTOMER)(15)

Gamma Exposure, ergs g^{-1}(C)	Temperature Treatment, F/hr	Specific Gravity at 25 C		Compression Set, %	Hardness, Shore A		Tensile Strength, psi	Ultimate Elongation, %
		Before	After		Before	After		
0	75/67			73.8			4648.4	623.8
3.2×10^8	75/2	1.225	1.238	64.4	96.5	96.7	4454.0	597.7
1.2×10^9	75/2	1.223	1.254	72.8	96.5	96.0	4062.0	580.0
2.7×10^9	75/6.7	1.225	1.239	84.2	96.7	97.0	3413.2	523.8
8.3×10^9	75/6.7	1.225	1.232	91.9	97.0	97.2	2698.2	432.1
2.8×10^{10}	75/67	1.227	1.240	93.6	97.0	98.0	1931.7	116.5
9.4×10^{10}	75/67	1.226	1.234	94.5	96.5	92.5	1967.8	42.1
0	210/2	1.226	1.217	100.4	96.3	89.0	4175.9	606.6
2.7×10^8	210/2	1.225	1.237	99.3	96.5	96.3	4150.9	582.1
9.7×10^8	210/2	1.224	1.235	101.2	97.0	96.5	3431.8	512.7
0	240/6.7	--	--	101.6	96.0	91.2	--	--
2.9×10^9	240/6.7	1.225	1.225	102.8	96.5	96.3	3023.9	492.2
1.1×10^{10}	250/6.7	1.229	1.211	114.8	96.5	93.8	2648.0	414.0
0	250/70	--	--	105.1	96.0	92.0	--	--
2.4×10^{10}	250/67	1.226	1.195	107.5	96.0	78.2	1542.3	123.9
8.0×10^{10}	250/67	1.226	1.225	106.7	95.8	84.8	1751.2	50.5

(a) Total time in compression for all specimens, 312 hours.

(b) Tensile values are average for 15 samples; all others are average for 5 samples.

TABLE 29. SUMMARY OF EFFECTS OF IRRADIATION AT TWO TEMPERATURES ON FLEXIBLE POLYURETHANE FOAM (BLOWN POLYETHER URETHANE, GENERAL FOAM CO.)[15]

Gamma Exposure, ergs g^{-1}(C)	Temperature Treatment, F/hr	Density, lb/ft^3	Compression Set[a], %	Compression Deflection[b] psi
0	75/67	2.65	7.67	0.500
3.2×10^8	75/2	2.57	4.70	0.565
1.2×10^9	75/2	2.75	19.42	0.[illegible]35
2.7×10^9	75/6.7	2.62	77.39	0.466
8.[illegible] x [illegible]	75/6.7	2.51	95.99	0.340
[illegible].8 x 10^{10}	75/67	2.67	100.34	0.171
[illegible].4 x 10[illegible]	75/67	2.86	(c)	0.034
0	210/2	2.36	69.3[illegible]	0.591
2.7×10^8	210/2	2.50	77.37	0.602
9.7×10^8	210/2	2.46	82.23	0.542
0	240/6.7	2.30	99.69	0.638
2.9×10^9	240/6.7	2.48	99.02	0.525
1.1×10^{10}	240/6.7	[illegible].59	100.33	0.407
0	250/67	2.33	103.29	0.764
2.4×10^{10}	250/67	2.64	102.66	0.330
8.0×10^{10}	250/67	3.14	100.0[c]	0.223

(a) Compressed to 50 per cent deflection during irradiation and for time period of 312 hours. Average of 6 samples.
(b) Load required for 25 per cent compression of 1-sq-in.-specimen area. Average of [illegible] samples.
(c) Highest exposure groups adhered to plates. Some could not be removed. Also shrank in size.

Modulus was not greatly affected by radiation. Swelling measurements indicated that a greater degree of crosslinking occurred during irradiation in vacuum than in air. Specimens showed no loss of transparency after irradiation, but the pale amber color was considerably intensified at the higher doses. No voids or bubbles were formed. Data are shown in Figures B-2 to B-5.

Heitz, et al.,[47] examined a polyurethane vulcanizate for stability to nuclear radiation and ultraviolet radiation in air and in vacuum. He found that the samples underwent an initial crosslinking period after which chain scission was more predominant. The difference between air and vacuum irradiation appeared very small. The weight changes were also small in view of the extensive degradation of some of the specimens. Regarding its resistance to gamma radiation alone, Heitz found that it compared with the best of the silicones evaluated. Data are given in Table B-51.

DeWitt, et al.,[9] tested Adiprene L and C for effects of exposure to vacuum and elevated temperatures (200 and 300 F for L and C, respectively). He found either no change or an increase in tensile strength, hardness, and elongation. Vacuum pressure obtained with Adiprene L would suggest that quite a bit of outgassing occurred.

Ossefort and Ruby[45] found that 5 days' exposure to vacuum at 300 F did not significantly affect tensile strength, although elongation decreased about 50 per cent. Hardness increased from 56 to 80. Exposure to the same temperature in air decreased tensile strength by almost 65 per cent, but did not change hardness. Data are given in Table B-52.

<u>Effects of Radiation and Fluid Immersion</u>

Wattier, Newell, and Morgan[48] irradiated four polyurethane elastomers while immersed in selected fluids. Those included:

Mil-L 7808	A phenoxy phenyl ether
4P3E	A diester oil
Oronite 8515	A nonpetroleum-base hydraulic fluid

Samples were immersed for approximately 1 month prior to irradiation and soaked for 2 months after irradiation. Data obtained were of a preliminary nature only, and no conclusions were drawn except that irradiation in 4P3E fluid appeared to cause more degradation than irradiation in the other fluids used. Data are shown in Tables B-53 through B-56.

Silicone Rubbers

The tensile strength of silicone rubber increases with irradiation in air up to an exposure of approximately 10^9 ergs g^{-1}(C), then it rapidly decreases. Elongation is the property most affected by radiation. Most silicones retain 50 per cent elongation after exposure to 5×10^9 ergs g^{-1}(C) at room temperature, 10^9 ergs g^{-1}(C) at 150 C, and 5×10^8 ergs g^{-1}(C) at 200 C.

Nitrile silicone retained useful properties when irradiated in fluids such as Oronite 8515, MIL-L-7808, and JP-4 fuel to an exposure of 10^{10} ergs g^{-1}(C).

Changes in tensile properties of silicone elastomers due to vacuum irradiation (gamma) are, in general, equivalent to or somewhat greater than the changes induced by irradiation in air.

Vacuum exposure to 600 F for 5 days had no appreciable effect on tensile strength of silicon elastomers, although exposure in air reduced this property by about 50 per cent. Elongation was not greatly affected.

The surface of silicone rubber shows crazing and discoloration on exposure to ultraviolet radiation.

Radiation-effects data have been obtained on the following types of commercially available silicone rubbers: dimethyl, methyl phenyl, methyl vinyl, methyl phenyl vinyl, methyl trifluoropropyl, and nitrile siloxanes. Of these, the nitrile and methyl phenyl silicone vulcanizates suffer the least damage when exposed to gamma radiation in air while the methyl trifluoropropyl type experiences the greatest damage. The methyl vinyl and methyl phenyl vinyl silicones are intermediate with respect to radiation stability. REIC Report No. 21 gives more detailed information regarding these types. Additional information covered in this addendum includes effect of temperature and gamma radiation-vacuum and gamma radiation, and some data on the effect of ultraviolet radiation.

Effects of Radiation and Temperature

Wattier, Newell, and Morgan[48] irradiated six silicone elastomers at -65 F, 80 F, and 350 F. The materials were stored at the same temperatures until testing. Testing was at -65 F, 80 F, and 300 F. Table 30 shows the changes in ultimate strength due to irradiation at the three temperatures. Additional tensile data are presented in Appendix B, Tables B-57 through B-63, for the control and irradiated specimens. An examination of these tables will show that all silicone rubbers tested gave evidence of extensive crosslinking, even when irradiated at -65 F. Ultimate strength increased with exposure to a certain point, generally about 10^9 ergs g^{-1}(C), and then decreased with increasing exposure. This decrease appeared to be quite rapid above 10^9 ergs g^{-1}(C), as shown by comparing the above tables with Tables B-64 through B-67. The increase in tensile strength was considered to be a continuation of the crosslinking that was not fully completed by the usual curing process and the decrease was attributed to chain cleavage. Tear strength decreased with increasing dose. It may be noted that the tensile properties were sensitive to the test temperature, tensile strength decreasing considerably at the 300 F temperature.

Two silicone rubbers, a methyl phenyl vinyl type (DC-916) and a nitrile silicone (NSR-X5602), were cycled under compression during radiation. A nitrile elastomer (Hycar 1001) was also tested for comparison. Data on the number of cycles and the compressive strengths are given in Table B-68. The cycling of the material was found to have an effect on the nitrile silicone and the nitrile rubber. Compression set for NSR-X5602 and Hycar 1001 was less for the cycled-compressed environment than for the static-compressed environment. No difference was found for DC-916.

Dexter and Curtindale at Dow Corning Corporation[36] determined the combined effects of gamma radiation and high temperatures on the electrical and physical properties of liquid, semisolid, elastomeric, and resinous silicones. These tests indicated that many silicone dielectrics exhibit appreciable resistance to changes in

properties induced by exposure to gamma radiation at temperatures ranging from 150 C to 200 C.

These investigators state that the tensile strength of silicone rubbers, e.g., Silastic 1602, was unaffected by irradiation at room temperature and at 150 C to 10^{10} ergs g^{-1}(C), while irradiation at 200 C decreased tensile strength (see Figure B-6). In all cases, hardness of the silicone elastomers increased with dose, the rate of increase being greater at elevated temperatures. Ultimate elongation is the property most affected by irradiation. Most silicone elastomers retain 50 per cent elongation after exposures of 5×10^9 ergs g^{-1}(C) at room temperature, 10^9 ergs g^{-1}(C) at 150 C, and 5×10^8 ergs g^{-1}(C) at 200 C. Dexter and Curtindale state that an experimental radiation-resistant stock retained 50 per cent elongation after 9×10^9 ergs g^{-1}(C) and 340 hours at 200 C, indicating a life in radiation fields 15 times greater than that of conventional silicone elastomers.

Electrical properties examined by these investigators included dielectric constant, dissipation factor, volume resistivity, and electric strength. The increase in dielectric constant of silicone elastomers irradiated at high temperatures was found to be less than that of the same materials irradiated at room temperature. The increase was of such magnitude as to cause only a slight change in the operating characteristics of the materials. Dissipation factor was affected in a similar manner, but did not change sufficiently to affect its operation in electrical equipment. Radiation exposure either at room temperature or high temperature did not significantly affect the volume resistivity or electric strength of the silicone elastomers at these exposures [10^{10} ergs g^{-1}(C)]. The effect of radiation at 25 C, 150 C, and 200 C on the electrical properties of Silastic 1602 are shown in Figure B-7.

Effects of Radiation and Fluid Immersion

A nitrile silicone (General Electric NSR-S5602) was tested by Wattier, Newell, and Morgan(48) in a combination of fluid, temperature, and irradiation environments. Specimens tested in fluids were immersed for approximately 7 days prior to irradiation and 30 days after irradiation. Samples were then tested within 4 hours after removal from the fluid. Data are given in Tables B-66 and B-67. Degradation of the silicone was noted in fluid MIL-L-7808, as indicated by the decrease in stress at 50 per cent elongation with exposure. Irradiations in Oronite 8515 and air resulted in an increase in stress at 50 per cent elongation with increasing exposure up to the maximum given [about 10^9 ergs g^{-1}(C)]. There did not appear to be any major difference between the tensile values obtained for the samples irradiated at 260 F and those irradiated at 80 F. Tests were run only at 80 F for JP-4 fuel immersion. In all cases, the nitrile silicone appeared to retain usable properties when immersed in these fluids after a radiation dose of 10^{10} ergs g^{-1}(C).

Effects of Radiation and Vacuum

Silicone elastomers have been subjected to vacuum at room and at elevated temperatures. In general, outgassing and equilibrium-weight-loss rates are relatively low and properties are not seriously affected. According to Jaffe and Rittenhouse(51), the temperature for 10 per cent weight loss per year in vacuum for silicone rubber is 200 C

TABLE 30. EFFECT OF NUCLEAR RADIATION AND TEMPERATURE ON TENSILE STRENGTH OF SILICONE ELASTOMERS(48)

Silicone	Chemical Type	Temperature of Irradiation and Testing[a], F	Gamma Exposure, ergs g^{-1}(C)	Tensile Strength, psi
DC-80	Methyl vinyl	-65	0	1303
			1.1×10^{9}	1238
		80	0	1057
			7×10^{8}	1117
		300	0	538
			1.6×10^{9}	631
SE-361	Methyl vinyl	-65	0	1050
			1.1×10^{9}	1354
		80	0	967
			1.6×10^{9}	953
		300	0	541
			1.6×10^{9}	[illegible]
DC-675	Methyl phenyl vinyl	-65	0	1090
			7×10^{8}	944
			1.1×10^{9}	1109
		80	0	992
			1.6×10^{9}	936
		300	0	533
			1.6×10^{9}	670
DC-916	Methyl phenyl vinyl	-65	0	(1589)
			1.1×10^{9}	404
		80	0	1504
			1.6×10^{9}	1182
		300	0	489
			1.3×10^{8}	772
			1.6×10^{9}	322
			1.1×10^{9}	611

TABLE 30. (Continued)

Silicone	Chemical Type	Temperature of irradiation and Testing[a], F	Gamma Exposure, ergs g^{-1}(C)	Tensile Strength, psi
SE-551	Methyl phenyl	-65	0	1404
			7×10^8	1515
			1.1×10^9	1259
		80	0	976
			7×10^8	1078
			1.6×10^9	883
		300	0	416
			1.6×10^9	544
LS-53	Methyl trifluoropropyl	-65	0	2052
			1.1×10^9	1076
		80	0	1289
			1.6×10^9	[illegible]
		300	0	472
			1.6×10^9	243

(a) Samples tested at 300 F were irradiated and stored at 350 F.

(400 F). Podlaseck and Suhorsky[4] give the following data for equilibrium-weight-loss rates:

Temperature, C	Pressure, torr	Equilibrium Weight Loss Rate, $g/(cm^2)(sec)$
177	760	3.9
	5×10^{-2}	2
	10^{-5}	ND
204	760	46.8
	5×10^{-2}	9.6
	1.6×10^{-2}	
	10^{-5}	
232	760	74.9
	9.5×10^{-1}	11.3
	6×10^{-2}	7.2
	10^{-5}	5.7

Outgassing rates as given by these investigators[4] are shown in Table 31. In general, these rates are low, and silicones are useful in vacuum environment. In areas where outgassing and possible recondensation may present problems, such as on optical surfaces and electrical contacts, silicones may be preferred over other elastomers and plastic materials. Although silicone rubber has a relatively high permeability rate, loss of gas from pressurized vehicles due to permeability is so small that it may be disregarded in most cases.

TABLE 31. OUTGASSING RATES OF SILICONE ELASTOMERS[4]

Elastomer	Outgassing Rate, torr-liters/sec/sq cm x 10^7		
	After 1 Hr	After 4 Hr	After 24 Hr
Silicone rubber (Wacker R60)	70	17	--
Silicone rubber (Wacker R80)	180	41	--
Silicone rubber (24 hours, 95 per cent humidity)	230	46	--
Silicone rubber (outgassed + 24 hours dry N_2)	13	--	--
Silastic	25	6	--
Silicone rubber	94	31	--
Silastic X6145C	25	5.6	--
Silastic 8-104 (red, 62 durometer)	12	3.7	--
Silastic 80 (white, cured 24 hours at 480 F, 74 durometer)	28	6.0	--
Silastic 50 (white, 55 durometer)	30	6.4	--
Silastic 67-163 (red, 61 durometer)	19	5.4	--
Silicone (red)	--	--	0.44
Silicone (green)	--	--	0.44

Boundy[31] listed the weight loss of several silicones after exposure to temperatures of 105 F and 300 F at a pressure of 10^{-6} torr after a period of 7 days. Values are

given in Table B-69. Per cent weight loss was in the order of 1.5 per cent. Boundy noted that an appreciable decrease in vacuum weight loss was noted when the rubber was postcured, especially if the postcure temperature was higher than the use temperature.

Fulk and Horr[17] reported the stationary-state weight-loss rate at 50 C for several silicone rubbers as well as the weight loss occurring before they reached a stationary state. Data are given in Table B-70. Stationary-state values were of the order of magnitude of 10^{-5} g/sq cm/hr. Weight loss to reach stationary state varied from 4.2 to 5.8 x 10^{-3} g/sq cm for the elastomers. In general, a steady-state weight loss was reached in 44 to 68 hours.

Ossefort and Ruby[45] exposed 2 methyl vinyl silicone rubbers to temperatures from 400 to 700 F. Vacuum exposure to 600 F for 5 days had no appreciable effect on tensile strength, although on exposure in air, this property was reduced by about 50 per cent. Elongation was not greatly affected in vacuum exposure. Weight losses were higher at these temperatures but this was also true in oven aged samples. One of the silicones maintained almost 50 per cent of its tensile strength when exposed to 700 F in vacuum. In air at this temperature, samples were too brittle to be tested. Data are given in Table B-71. In general, the effect of elevated temperatures was greater in air than in vacuum.

Heitz and coworkers[47] irradiated silicone elastomers in air and in vacuum with gamma radiation. They found that atmospheric conditions as compared with vacuum environment did not cause many significant differences in radiation effects on these materials. Where such differences did occur, gamma radiation in vacuum produced greater cross-linking in the dimethyl, dimethyl phenyl, and dimethyl vinyl types than radiation in air. The reverse was true of the methyl phenyl vinyl compound tested. Tables B-72 through B-85 show the effect of radiation in air and in vacuum on tensile strength, 100 per cent modulus, ultimate elongation, hardness, and weight change for six types of elastomers. The values after 100 hours of radiation are compared for these rubbers in Table 32. It may be seen that changes in properties due to gamma radiation in vacuum were, in general, equivalent to or somewhat greater than those in air.

These data are in general agreement with the findings of McGarvey[52] who studied the effects of radiation in air, oxygen, argon, and vacuum on various silicone elastomers and found that the media had little influence on the vulcanizate's physical properties at the exposures employed [10^{10} ergs g^{-1}(C)].

Heitz indicated that room-temperature vulcanizing compounds as a class, with one exception, were the most radiation resistant of the silicones. However, it should be pointed out that tensile strength of these materials was lower than that of the high-temperature-cured materials (see Table 32).

Effects of Ultraviolet Radiation

Podlaseck and Suhorsky[4] investigated the effect of ultraviolet and vacuum at 26 C and 53 C on the permeability of silicone rubber. No significant changes in the permeability rates were found, but the silicone rubber showed surface crazing as a result of the ultraviolet exposure. Ultraviolet exposure was equivalent to approximately 1300 hours of solar radiation for the samples tested at 53 C and about 24 hours for the samples tested at 26 C.

TABLE 32. EFFECT OF GAMMA RADIATION AND VACUUM ON SILICONE ELASTOMERS[47]

Compound	Curing Data	Nominal Irradiated Conditions(a)	Gamma Exposure, ergs g⁻¹(C)	Tensile Strength, Psi	Tensile Strength, Per Cent Chg.(b)	100 Per Cent Modulus, Psi	100 Per Cent Modulus, Per Cent Chg.(b)	Ultimate Elongation, Per Cent	Ultimate Elongation, Per Cent Chg.(b)	Hardness, Duro A	Hardness, Chg.(b)	Weight Change, mg
106-62	Postcured 12 hr at	As cured	None	[illegible]		193		387		58		
Dimethyl	480 F	Gamma, air	3.4×10^9	[illegible]	-9	1016	+426(c)	120	-69	78	+20	+2
		Gamma, vacuum	6.2×10^9	600	-51	--	+564	47	-88	74	+16	+33
105-62	Press cured 5 min at	As cured	None	819		--		62		83		--
Dimethyl	240 F	Gamma, air	3.4×10^9	1210	+48	--	+205(c)	30	-52	87	+4	+1
	Postcured 24 hr at 480 F	Gamma, vacuum	6.2×10^9	[illegible]	+28	--	+298(c)	20	-68	92	[illegible]	+6
39-62 Dimethyl vinyl	Postcured 24 hr at	As cured	None	731		449		210		67		
	410 F	Gamma, air	4.1×10^9	838	+15	--	+196(c)	57	-63	81	+14	+2
		Gamma, vacuum	4.9×10^9	787	+7.6	--	+150(c)	63	-70	73	+6	+4
107-62	Postcured 24 hr at	As cured		859		523		150		64		
Dimethyl vinyl	480 F	Gamma, air	3.4×10^9	926	+7.8	--	+164(c)	67	-55	75	+11	+3
		Gamma, vacuum	6.2×10^9	655	-24	--	+213(c)	40	-73	80	+16	+1
111-62	Postcured 24 hr at	As cured		1029		415		227		73		
Dimethyl vinyl	480 F	Gamma, air	3.4×10^9	1151	+12	--	+340(c)	63	-72	--	+10	+4
		Gamma, vacuum	6.2×10^9	816	-21	--	+318(c)	47	-79	87	[illegible]	+4
109-62	Postcured 4 hr at	As cured		1473		229		500		62		
Methyl phenyl	480 F	Gamma, air	3.4×10^9	992	-32		+337	30	-82	76	+14	+3
vinyl		Gamma, vacuum	6.2×10^9	774	-48		+404(c)	67	-87	78	+16	+3
56-62	Press cured 10 min at 250 F	As cured		1169		208		403		50		
Dimethyl	Postcured 3 hr at	Gamma, air	3.4×10^9	692	-41	737	+254	93	-77	67	+17	+6
phenyl	400 F	Gamma, vacuum	6.2×10^9	660	-41		+323(c)	75	-82	76	+26	0
58-62	Press cured 10 min at 250 F	As cured		1147		117		383		53		
Dimethyl	Postcured 24 hr at	Gamma, air	3.4×10^9	742	-35		+424(c)	80	-80	70	+17	+5
phenyl	480 F	Gamma, vacuum	6.2×10^9	777	-32		+458(c)	75	-81	76	+23	+2

TABLE 32. (Continued)

Compound	Curing Data	Nominal Irradiated Conditions(a)	Gamma Exposure, ergs g^{-1}(C)	Tensile Strength		100 Per Cent Modulus		Ultimate Elongation		Hardness		Weight Change, mg
				Psi	Per Cent Chg.(b)	Psi	Per Cent Chg.(b)	Per Cent	Per Cent Chg.(b)	Duro A	Chg.(b)	
110-62 Methyl trifluoro propyl	Postcured 16 hr at 300 F	As cured		346		371		243		62		
		Gamma, air	4.1×10^9	374	-72		+50(c)	67	-72	73	+11	-8
		Gamma, vacuum	6.2×10^9	382	-72		+54(c)	67	-72	72	+10	-8
120-62 Dimethyl	Room-temperature-vulcanized silicone	As cured		674		503		147		62		
		Gamma, air	3.4×10^9	688	+2.1		+95(c)	70	-52	72	+10	+2
		Gamma, vacuum	5.0×10^9	573	-15		+100(c)	57	-61	75	+13	
147-62 Dimethyl	RTV, 95 parts compound, 4 parts curing agent	As cured		282		203		167		51		
		Gamma, air	3.4×10^7	211	-25		+352(c)	23	-86	68	+17	-8
		Gamma, vacuum	6.2×10^9	541	+92		+344(c)	60	-64	73	+22	-18
148-62 Dimethyl	RTV, 100 parts compound, 0.5 parts Thermolite T-12	As cured		409		232		143		54		
		Gamma, air	3.4×10^9	329	-20		+77(c)	80	-44	60	+6	-5
		Gamma, vacuum	6.2×10^9	315	-23		+76(c)	77	-46	65	+11	-2
149-62 Dimethyl	RTV, low density 100 parts compound, 10 parts accelerator	As cured		266				90		64		
		Gamma, air	3.4×10^9	211	-21		+52(c)	47	-48	73	+9	+18
		Gamma, vacuum	4.9×10^9	288	+8.3		+62(c)	60	-33	75	+11	-2

(a) Samples irradiated for 100 hours at "0 F.
(b) From as-cured value.
(c) Value found by extrapolation.

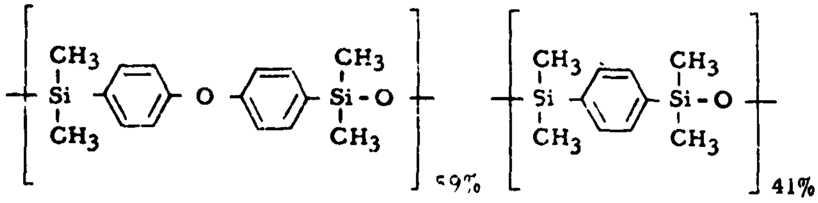
Heitz[47] found that combined radiation (gamma and ultraviolet) caused more crosslinking than straight gamma radiation, the differences ranging from slight to marked. The evaluation of this, however, is complicated by the fact that the ultraviolet radiation was accompanied by high temperatures. Since heating in vacuum causes chain scission of silicone compounds, and it was not possible to cool the specimens to room temperature, Heitz acknowledges that a straightforward evaluation of the changes caused only by the ultraviolet radiation was very difficult. However, specimens exposed to ultraviolet light showed a marked discoloration of the surfaces toward the lamp, thus indicating an ultraviolet-radiation-induced reaction. Data are given in Tables B-72 through B-85.

Studies to Improve Radiation Stability

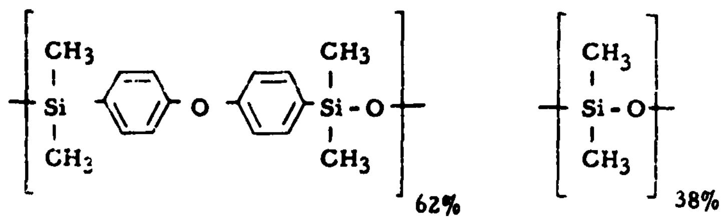
The incorporation of arylene groups in the backbone structure of the silicone molecule appears to be promising for improved radiation resistance. Ossefort[53] and McGarvey[52] at Rock Island Arsenal studied the thermal and radiation stability of arylene-modified siloxanes prepared by Union Carbide Corporation. On the basis of this work, it appears that the incorporation of arylene structures in the main chain does not contribute to their thermal stability or to their elevated-temperature properties. However, aryl-ether aryl and aryl-ether dimethyl silicones were found to possess significantly better initial physical properties than did the conventional silicones and were significantly better than any of the commercial types evaluated with respect to radiation stability. Figure 16 shows the chemical structure of the arylene-modified materials. The aryl-ether aryl vulcanizate retained some useful properties at exposures up to 3 x 10^{10} ergs g^{-1}(C) in both vacuum and in air. Figure 17 shows a comparison of the effect of gamma radiation on ultimate elongation of these materials as compared with those of methyl phenyl silicone and dimethyl silicone. Following is a comparison of the effect of radiation on the several types of silicone rubbers as found by McGarvey.

Radiation Resistance	Elongation After Exposure of 5 x 10^9 ergs g^{-1}(C)	Type of Silicone
Good	>50% of initial value	Aryl-ether aryl
		Aryl-ether dimethyl
Fair	<50%, >20% of initial value	Nitrile
		Aryl dimethyl
		Methylphenyl
		Methylphenylvinyl
		Methylvinyl
Poor	<20% of initial value	Methyltrifluoropropyl

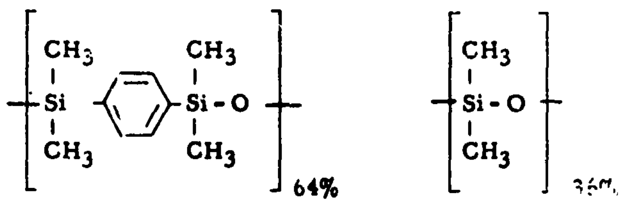
It was also determined that the physical properties of the arylene-modified silicones cured by gamma radiation were equal to or better than those obtained with a peroxide-type cure. A dose of approximately 10 megarads produced optimum cures in the aryl dimethyl and the aryl-ether aryl silicones, and about 15 megarads produced the optimum cure for the aryl-ether dimethyl type.



Aryl-Ether Aryl



Aryl-Ether Dimethyl



Aryl Dimethyl

FIGURE 16. ARYLENE-MODIFIED SILICONES

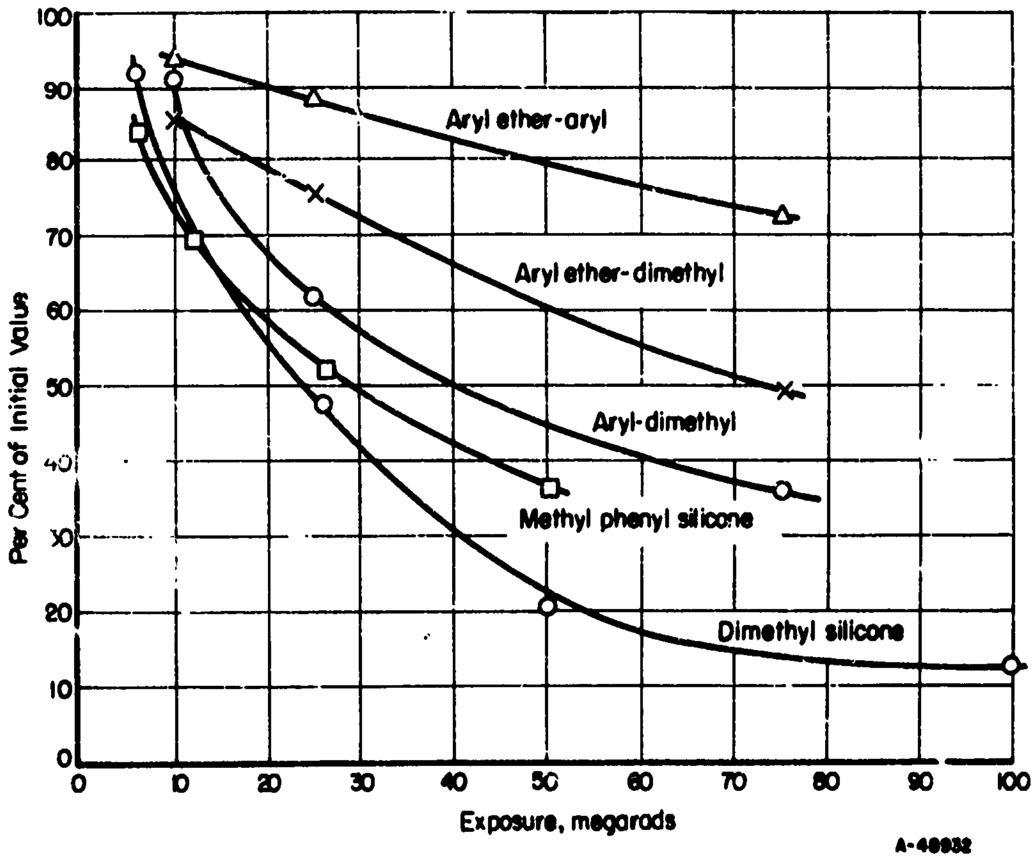
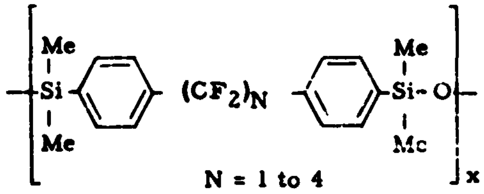
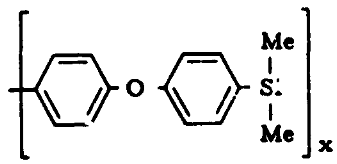


FIGURE 17. EFFECT OF GAMMA RADIATION ON THE ULTIMATE ELONGATION OF VARIOUS SILOXANES

Two other phases of the program included the preparation of arylene-modified siloxanes connected by perfluoromethylene groups (Standford Research Institute) and the preparation of arylene-modified silcarbanes (Yarsley Research Laboratories, London). The structures of these materials are indicated in Figure 18. Data on these modifications are not yet available.



Fluorinated-Arylene-Modified Polysiloxane



Arylene-Modified Silcarbanes

FIGURE 18. SILOXANE AND SILCARBANE POLYMERS

Antirads

A considerable amount of work has been performed to improve radiation resistance of polymers by using antirads. Work has been done on the investigation of antirads at Mare Island Naval Shipyard and at Rock Island Arsenal. Morris and Caggegi at the naval shipyard investigated 93 antirads in an effort to develop rubber gaskets which would be resistant to nuclear radiation, and McGarvey at the arsenal evaluated approximately 200 potential antirads to determine the best one for low-acrylonitrile-content nitrile (NBR) rubber.

Morris and Caggegi[40] were interested in improving the compression-set properties of gaskets. They found that improvement could be obtained by compounding with certain antioxidants, antiozonants, or with certain chemicals containing aromatic rings or condensed ring structures. Akroflex C, AgeRite HP, and Santoflex GP were among the best antioxidants for improving the radiation stability of Synpol 1500 (SBR). Those antioxidants having the best antirad properties were derivatives of p-phenylene diamine, phenyl naphthylamine, or a blend of these chemicals.

Some of the antirads which were good in Synpol 1500 were among the best also in Hycar 1072 (nitrile rubber). Examples were Wingstay 100, Akroflex C, Akroflex CD, and AgeRite HP. Antirads which were not outstanding in Synpol 1500 but which were quite good in Hycar 1072 and Hycar 1041 were Santovar A, Ionol, and Deenax. All of these are phenolic derivatives.

Vulcanizates were further improved in radiation resistance when both an antioxidant and a plasticizer with an aromatic ring structure were incorporated in the rubber stocks. Five parts of Thermoflex A and 10 parts of dibenzyl phthalate lowered compression set of Synpol 1500 from 74 per cent to 48 per cent after irradiation. It was necessary to compound stocks with more carbon black to maintain the Shore hardness of the plasticized vulcanizates within the range of 65 to 75.

Naphthalene was a plasticizer which was particularly effective in combination with an antirad for nitrile rubber (Hycar 1072). AgeRite Hipar (5 parts) and Naphthalene (10 parts) gave a vulcanizate with a compression set of 53 per cent after irradiation. Compression set of irradiated vulcanizates of Hycar 1072 without these additives was 80 per cent and that for Hycar 1072 with AgeRite Hipar was 65 per cent.

Acridine, pyrene, and fluoranthene were other plasticizers which provided improved radiation with antirads in Synpol 1500. Acridine was also outstanding with antirads in Hycar 1072. These antirads are listed, with the chemical composition and name of the supplier, in Tables 33 and 34.

McGarvey(54) evaluated antirads on the basis of per cent of initial NBS strain and Shore A hardness values after an exposure of 5×10^9 ergs g^{-1}(C). The compounds whose vulcanizates met the following requirements after irradiation were judged to possess significant antirad activity:

NBS strain, 50 per cent, >50 per cent of initial value
Ultimate elongation, 200 per cent, >50 per cent of initial value
Ultimate tensile strength, >2000 psi.

Table 35 lists the 12 best antirads arranged in descending order according to their antirad activity. From this table it can be seen that several aromatic nitro compounds function as inhibitors of radiation damage in NBR rubber. In particular, 2,2-diphenyl 1-picrylhydrazyl (DPPH) and 1,1-diphenyl-2-picrylhydrazine ($DPPH_2$) appear to be the most efficient antirads. The mechanism of their protective action was attributed to their function as radiation-stabilised scavengers for free radicals produced by high-energy radiation. It is not known how DPPH and $DPPH_2$ may attach to the free radicals produced in the NBR vulcanizate.

The antirad activity of $DPPH_2$ present at a concentration of 5 phr was also investigated in SBR, Butyl rubber, and natural rubber. A significant antirad activity was exhibited in only the SBR vulcanizate, as can be seen from Table 36.

TABLE 33. ANTIRADS FOR STYRENE-BUTADIENE (SBR) RUBBER[40]

Name	Chemical Composition (Supplier's Description)	Supplier
	Antioxidants and Antiozonants	
Akroflex C	Diphenyl-p-phenylenediamine + phenyl-alpha-naphthylamine	E. I. du Pont de Nemours & Co.
AgeRite HP	Phenyl-beta-naphthylamine + diphenyl-p-phenylenediamine	R. T. Vanderbilt Co.
Santoflex GP	N-Cyclohexyl-N'-phenyl-p-phenylenediamine	Monsanto Chemical Co.
Wingstay 100	Alkyl aryl amine	Goodyear Tire and Rubber Co.
Akroflex CD	Diphenyl-p-phenylenediamine + phenyl-beta-naphthylamine	E. I. du Pont de Nemours & Co.
Thermoflex A	Di-p-methoxydiphenylamine + diphenyl-p-phenylenediamine + phenyl-beta-naphthylamine	E. I. du Pont de Nemours & Co.
	Plasticizers	
Dibenzyl phthalate	Dibenzyl phthalate	Eastman Chemical Products
	Miscellaneous	
Acridine	Acridine	Eastman Chemical Products
Pyrene	Pyrene	Reilly Tar & Chemical Corp.
Fluoranthene	Fluoranthene	Reilly Tar & Chemical Corp.

TABLE 34. ANTIRADS FOR NITRILE RUBBER

Name	Chemical Composition (Supplier's Description)	Supplier
	Antioxidants and Antiozonants	
Wingstay 100	Alkyl aryl amine	Goodyear Tire and Rubber Co.
Akroflex C	Diphenyl-p-phenylenediamine + phenyl-alpha-naphthylamine	E. I. du Pont de Nemours & Co.
Akroflex CD	Diphenyl-p-phenylenediamine + phenyl-beta-naphthylamine	E. I. du Pont de Nemours & Co.
AgeR[illegible]	Phenyl-beta-naphthylamine + diphenyl-p-phenylenediamine	R. T. Vanderbilt Co.
Santo[illegible]ar A	2,5-ditertiary-amyl hydroquinone	Monsanto Chemical Co.
Ionol	2,6-Di-tert-butyl-4-methyl phenol	Shell Chemical Corp.
Deenax	2,6 Di-tert-butyl-4-methyl phenol	Enjay Chemical Co.
AgeRite Hipar	Phenyl-beta-naphthylamine + isopropoxy diphenylamine + diphenyl-p-phenylenediamine	R. T. Vanderbilt Co.
	Miscellaneous	
Naphthalene	Naphthalene	Reilly Tar & Chemical Corp.
Acridine	Acridine	Eastman Chemical Products

TABLE 35. EVALUATION OF THE BEST ANTIRADS IN NBR

Additive (5 Phr Polymer)	Per Cent of Original Property After 5 x 10^7 Rads: Tensile	Elongation	Hardness, Shore A	Strain, NBS
None (Control)	92	33	116	34
2,2-Diphenyl-1-picrylhydrazyl	109	61	104	58
1,1-Diphenyl-2-picrylhydrazine	98	63	108	55
N,N'-Diphenyl paraphenylenediamine	82	51	110	55
1-Fluoro-2,4-dinitrobenzene	113	70	116	55
5-Nitro-1-naphthylamine	100	58	110	54
p-Phenylazoaniline	95	53	114	54
4-Phenylazodiphenylamine	91	51	112	53
2-Nitrodiphenylamine	97	51	112	52
Phenothiazine	93	51	115	52
p-Nitrobenzonitrile	97	52	118	52
p-Nitrobenzhydrazide	92	51	112	51
p-Nitrophenylhydrazine	113	60	113	50

TABLE 36. EVALUATION OF $DPPH_2$ IN VARIOUS ELASTOMERS

Polymer	Additive	Per Cent of Original Property After 5 x 10^7 Rads: Tensile	Elongation	Hardness, Shore A	Strain, NBS
SBR	None	98	55	117	51
"	$DPPH_2$	112	84	108	65
Butyl	None	4	71	59	--
"	$DPPH_2$	4	70	66	--
Natural	None	86	67	112	64
"	$DPPH_2$	80	71	106	78

PLASTICS

As was true with elastomers, most of the data collected on plastics since the publication of REIC Report No. 21 have been in connection with the materials used in various components for space vehicles or missiles. Effects of combined environments such as vacuum and radiation have been investigated. Most of this work was discussed in the section on components. However, those plastics for which new information was obtained are discussed alphabetically in this section.

Three new polymers have been developed that look promising with respect to radiation stability. These are the polyimides, poly n-vinyl carbazole, and the phosphonitrillic chlorides. More work needs to be done with these materials before it will be possible to determine their suitability for specific applications. Ultraviolet radiation is important in the use of plastics and deterioration can be serious under certain conditions of exposure.

Acrylics

Polymethyl methacrylate (Lucite or Plexiglas) is unaffected by gamma radiation to an exposure of 8.2×10^7 ergs g^{-1}(C), but tensile strength and elongation are decreased by 25 per cent at an exposure of 1.1×10^9 ergs g^{-1}(C). Physical properties deteriorate quite rapidly above that amount of radiation. Above 10^9 ergs g^{-1}(C) of absorbed radiation, polymethyl methacrylate becomes very brittle.

Information on acrylic polymers shows that work has been done on the effects of vacuum, temperature, and ultraviolet (UV) radiation on Plexiglas (methylmethacrylate) and on acrylic coatings. Data for the latter are presented in the section on coatings, and the information on the plastic is given here.

Effect of Ultraviolet Radiation

Wahl and Robinson[35] observed the effects of ultraviolet radiation (2 py:ons) and vacuum ($6.0 \pm 3 \times 10^{-6}$ torr) for periods of 100 hours. Properties observed were surface and color changes, spectral transmission, luminous transmittance, and haze. Hardness, loss in weight, and changes in chemical structure after irradiation were also determined. Data are given in Table 37. Also included for comparison is Selectron 400, a heat-resistant polyester, transparent glazing material. Wahl stated that the plastics irradiated in a vacuum became slightly translucent and the haze measurements are of questionable value.

After vacuum exposure alone, Plexiglas 55 and Selectron 400 specimens lost less than 0.8 per cent in weight and there was no measurable change in Barcol hardness. With ultraviolet and vacuum, Plexiglas lost less than 2 per cent in weight and hardness decreased slightly. Selectron 400 showed no significant weight loss but a considerable increase in hardness. The irradiated Selectron 400 became very brittle and shattered when indented with the Barcol hardness tester. The surface of the plastics turned brown.

TABLE 37. PROPERTIES OF VACUUM-IRRADIATED TRANSPARENT GLAZING MATERIALS BEFORE AND AFTER 100-HOUR EXPOSURE[35]

Material	Haze, per cent		Parallel Light Transmission, per cent		Weight Loss, per cent	Barcol Hardness	
	Before Exposure	After Exposure	Before	After	After	Before	After
Selectron 400	6.2	74.8	89.3	22.3	0.22	14	52
Plexiglas 55	4.8	68.7	90.9	20.0	1.89	58	54
Stretched Plexiglas 55	6.9	[illegible]0.0	89.2	5.0	1.80	59	54

Versluys, et al.,[55] also irradiated Plexiglas in vacuum with ultraviolet. Data are shown in Table C-1 of Appendix C. The outgassing was believed to be adsorbed nitrogen since the dissolved gas was found to be of mass 28. No discoloration was observed.

Ringwood[56] states that polymethyl methacrylate tends to unzip or depolymerize in a vacuum of 10^{-8} torr at ambient temperatures under exposure to rays shorter than 3800 A. In space this effect is accelerated by the increase in temperature in the plastic caused by the absorption of infrared rays. Surface discoloration and crazing have been observed under the same ultraviolet exposure but at higher pressures (10^{-6} torr) when tested in a chamber maintained at 72 F.

Temperatures at which there is 10 per cent weight loss per year are 40 to 150 C (100 to 300 F) for methylacrylate, and 100 to 200 C (220 to 390 F) for methylmethacrylate in vacuum. An acrylate (MIL-P-5425) showed 0.3 per cent weight loss on disiccation, an additional 0.03 per cent on vacuum exposure, and maintained 0.15 per cent (net weight loss) after re-exposure to air[57].

Acrylonitrile

Wilcox, et al.,[58] irradiated Acrilan in nitrogen with monochromatic light and irradiated samples with a G30T8 lamp in nitrogen and in a vacuum. Data are included in Tables C-2 and C-3. The shorter wavelengths produce greater changes in the tensile strength per joule of incident energy than the longer wavelengths produce. Tensile strength is degraded about 1.5 times as fast in nitrogen as in a vacuum. Jaffe and Rittenhouse[51] give 20 C (240 F) as the temperature for 10 per cent weight loss per year for acrylonitrile polymer.

Acrylonitrile/Butadiene/Styrene Terpolymer (ABS)

At room temperature, Kralastic MV (an ABS polymer) increased in tensile strength when irradiated to a gamma exposure of 2.8×10^{10} ergs g^{-1}(C). At 9.4×10^{10} ergs g^{-1}(C), tensile strength decreased by 30 per cent. At 250 F, the polymer lost two-thirds of its tensile strength at an exposure of 8×10^{10} ergs g^{-1}(C).

Lewis[15] determined the effects of irradiation on two types of ABS polymers at 75 F and at 250 F. These materials were Kralastic MV and Kralastic SRA plastics. At 75 F, both materials increased in tensile strength when irradiated to an exposure of 2.8×10^{10} ergs g^{-1}(C). At 9.4×10^{10} ergs g^{-1}(C), tensile strength decreased by approximately 30 per cent of the original. The MV material increased in tensile strength from 3730 psi to a maximum of 5070 psi and then decreased to 2140 psi. The tensile strength of SRA material increased from 4730 psi to 6330 psi and then decreased to 2820 psi. In both cases, hardness increased with increasing radiation exposure. At elevated temperatures this change takes place more rapidly, and at 250 F Kralastic MV, nonirradiated, has a tensile strength of 3670 psi, while after irradiation to an exposure of 8×10^{10} ergs g^{-1}(C) at 250 F tensile strength decreased to 1230 psi. Under the same conditions, the SRA material decreased from 4350 psi to 875 psi. Hardness of both materials increased with increasing radiation at the elevated temperatures in approximately the same fashion as it did when irradiated at room temperature.

Cellulose Acetate

Cellulose polymers are among the polymers least resistant to radiation damage. At an exposure of 1.9×10^{9} ergs g^{-1}(C), cellulose acetate has deteriorated by 25 per cent.

Weight-loss data for cellulose acetate and cellulose acetate butyrate only were found. Riehl[57] indicates that neither material lost weight in 24 hours in vacuum after first coming to constant weight in a disiccator.

Diallyl Phthalate

Diallyl phthalate has shown excellent radiation stability. For example, a case molded from diallyl phthalate Type FS80 which is flamepoof and long-glass-fiber filled was exposed to 4.3×10^{16} $nv_f t$ [the equivalent of 1.3×10^{10} ergs g^{-1}(C)]. The radiation resistance of this case was considered very good.[38] Also, coil forms, insulators, and standoffs were relatively unaffected at an exposure of 6.2×10^{12} ergs g^{-1}(C).

Although there are changes in electrical properties such as dielectric constant, dissipation factor, and volume resistance while exposed to a radiation flux, recovery of these properties after exposure is very good. Electrical leakage resistance of diallyl phthalate connectors was reduced to 0.1 of the initial value at an integrated exposure of 8.8×10^{12} ergs g^{-1}(C). The connectors were removed from the radiation field and within 15 minutes, leakage resistance had returned to the original value.[59,60] Table 38 shows the change in leakage resistance with exposure.

The effect of vacuum and temperature on diallyl phthalate was studied by Podlaseck and Suhorsky[4] and Fulk and Horr[17]. Data are presented in Tables C-4 and C-5. The effect of temperature on weight loss in air and in vacuum is shown in Figure 19. Diallyl phthalate has a very low equilibrium outgassing rate at moderate temperature similar to those of epoxies and polyesters. But like these, the initial rates are considerably higher than those for fluorocarbons, silicones, and Mylar.

TABLE 38. LEAKAGE RESISTANCE OF DIALLYL PHTHALATE CONNECTORS IN PILE - DYNAMIC TESTING[60]

Radiation Exposure, n cm^{-2} (E_n > 2.9 Mev)	Leakage Resistance[a], megohms at 55 C
None	56
1.68×10^{14}	36
5.04×10^{14}	41
1.34×10^{15}	33
2.27×10^{15}	12.5
3.36×10^{15}	6.8
5.12×10^{15}	5.8
6.47×10^{15}	5.2
9.24×10^{15}	5.9
9.58×10^{15}	5.1
1.31×10^{16}	6.2
1.43×10^{16}	6.8
1.67×10^{16}	6.8
Scram + 2 min	17.5
Scram + 22 min	40
Scram + 42 min	58
Scram + 237 min	90
Scram + 24 hours	110

(a) Initial leakage measurement before installation = 4000 megohms at room conditions; baseline leakage resistance = 56 megohms at 55 C.

Epoxy Resins

Epoxy resins are above average for plastics in radiation resistance, having withstood gamma exposures to 9.5×10^{10} ergs g^{-1}(C) without appreciable deterioration.

Aromatic-type curing agents provide the best irradiation resistance.

Epoxy resins have low-weight-loss equilibrium constants, although initial outgassing is somewhat greater.

Epoxy resins are considered for use in space applications primarily for laminates, adhesives, encapsulating or potting materials, and coatings. In general, epoxy resins have low-weight-loss equilibrium constants, although initial outgassing is somewhat greater. In this latter respect it is inferior to the fluorocarbons and silicone but superior to the phenolics.

Equilibrium-weight loss data[18] are given in Table C-4. A comparison of the initial rates of weight loss of several materials as given by Gloria et al.,[61] are shown in Figure C-1. Weight losses were also obtained by Fulk[17] and are given in Table B-70.

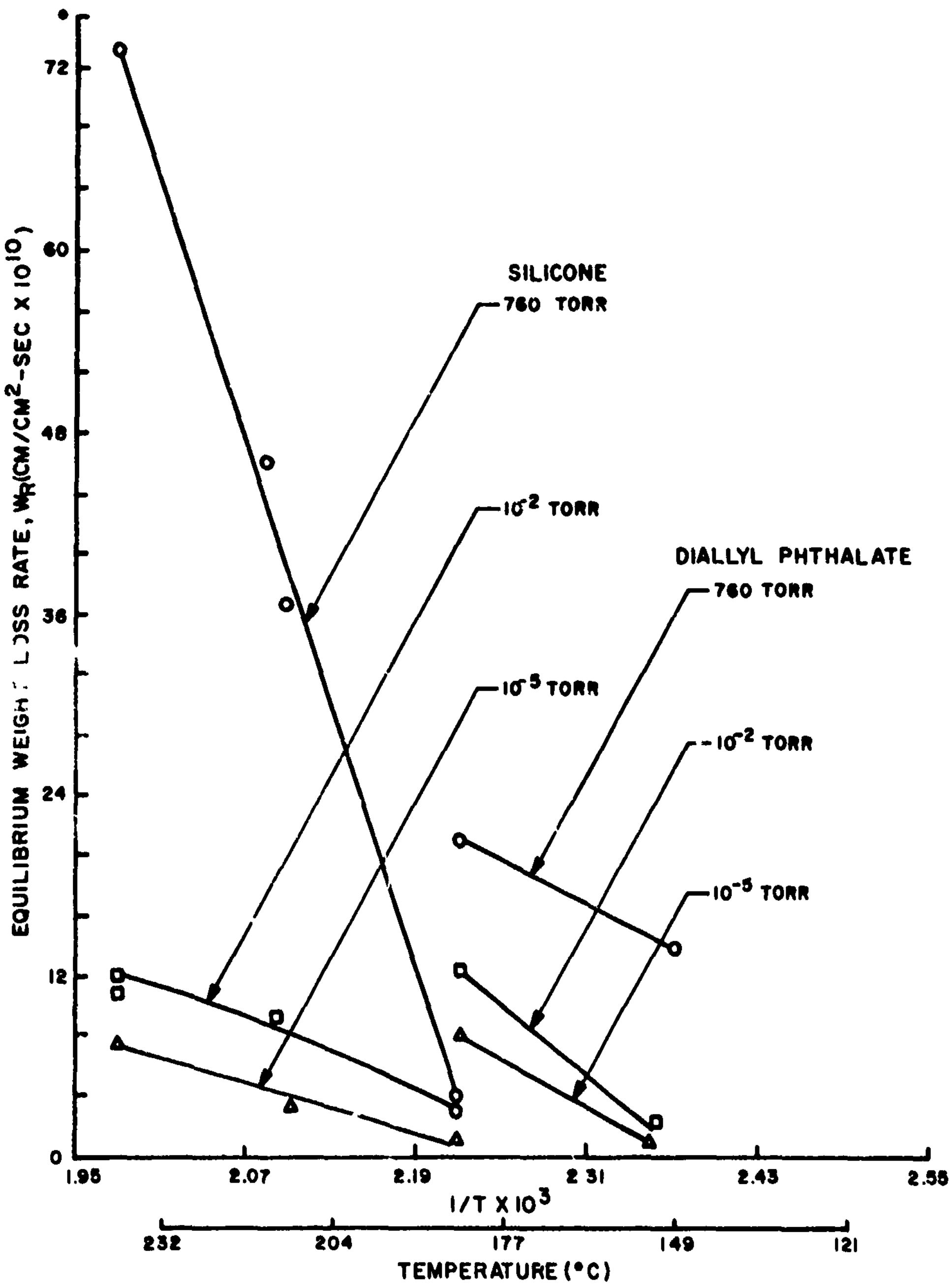


FIGURE 19. EFFECT OF TEMPERATURE ON WEIGHT LOSS IN AIR AND IN VACUUM(4)

At cryogenic temperatures, epoxies have the highest flexural strength, with phenolics and polyesters following in that order.(8)

Fluorocarbons

Teflon FEP 100 (a copolymer of hexafluoropropene and tetrafluoroethylene) is considerably more radiation resistant in air than is Teflon TFE (tetrafluoroethylene). Threshold damage for Teflon TFE in air occurs at 1.7×10^6 ergs g^{-1}(C), and 25 per cent damage is accrued at an exposure of 3.4×10^6 ergs g^{-1}(C).

In vacuum, tensile strength of Teflon TFE is satisfactory to 8×10^9 ergs g^{-1}(C).

Fiberglas reinforced Teflon retained 40 per cent of tensile strength and some flexibility at 1.2×10^{10} ergs g^{-1}(C) in air.

Tedlar (polyvinyl fluoride) as a 4-mil film showed good radiation resistance to an exposure of 10^{10} ergs g^{-1}(C), but decomposed and gave off a considerable quantity of HCl above that exposure.

Kynar(polyvinylidene fluoride) shows excellent retention of tensile strength when irradiated in air and in vacuum to 10^9 ergs g^{-1}(C).

Kynar is reported to have excellent resistance to ultraviolet radiation.

Fluorocarbons with their excellent temperature and chemical resistance and with good to excellent electrical characteristics are of great interest for space applications. Fluorocarbons for which information is available include Teflon TFE (polytetrafluoroethylene), Teflon FEP (a copolymer of hexafluoropropene and tetrafluoroethylene), Kel-F (chlorotrifluoropropylene), Tedlar (polyvinyl fluoride), and Kynar (polyvinylidene fluoride).

Teflon is probably the best illustration of the importance of considering all factors of space environment in determining the behavior of a material in space. Teflon has poor radiation resistance in air and originally this was believed to preclude its use for space applications. However, in an oxygen-free atmosphere (as in a vacuum) its radiation resistance is improved by about two orders of magnitude. It is being used successfully for many applications in satellites and numerous studies have been made to determine the behavior of this material in space. The following data show the results of these efforts. Most of the work has been with Teflon TFE, Teflon FEP and Kel-F. Limited data are available on Kynar and Tedlar. Comparative properties of the first three materials in air are shown in Table C-6, Appendix C.

Effects of Nuclear Radiation

In order to determine differences in radiation resistance among fluorocarbon polymers, Wattier, Newell, and Morgan(48) studied the radiation resistance of Teflon TFE, Teflon FEP 100, and Tedlar. They found that Teflon FEP 100 had considerably more radiation resistance in air than the standard TFE of the same thickness. Teflon FEP also shows greater stability in the absence of air, as can be noted in its radiation

resistance when immersed in Oronite 8515 or in helium. Fiberglas-reinforced Teflon showed good radiation resistance. This material retained some of its flexibility as well as 40 per cent of its tensile strength at a radiation exposure of 1.2×10^{10} ergs g^{-1}(C). Data are given in Tables C-7 through C-9.

Tedlar film decomposed and gave off a considerable quantity of HCl during irradiation. Radiation resistance of the 0.004-inch film was quite good up to an exposure of 1.0 to 1.4×10^{10} ergs g^{-1}(C). Data are included in Table C-10.

Effects of Nuclear Radiation and Vacuum

Golden and Hazell[50] irradiated Teflon in vacuum (10^{-6} torr). No change in color or opacity occurred at doses less than 1.3×10^{10} ergs g^{-1}(C), but above this dose, disks and film disintegrated. Polymers which had received a high radiation dose had a sharp melting point (327 C) and gave a clear colorless melt, whereas unirradiated material showed no visible change up to 400 C. Highly irradiated material evolved gas at and above the melting point.

Variation of tensile properties with increasing radiation dose are shown in Figure C-2. Table C-11 shows values as given by Shoffner[62]. It may be seen in Figure C-2 that tensile strength equivalent to that of unirradiated material is maintained up to an irradiation exposure of 8×10^{9} ergs g^{-1}(C). At higher exposures, the tensile strength, although somewhat erratic, is greatly decreased and at 1.2×10^{10} ergs g^{-1}(C) is reduced to a negligible value. However, elongation is reduced from 200 per cent for the unirradiated material to a few per cent after an exposure of 4×10^{9} ergs g^{-1}(C). Thus degradation reduces the extensibility before appreciably reducing tensile strength. Infrared spectrographs of unirradiated samples and of those irradiated in air and in vacuum have been made.[82] Table C-12 shows the differences in unirradiated and irradiated samples.

Kerlin[6,7] irradiated Teflon TFE and Kel-F in vacuum (2.5×10^{-7} torr) and tested the specimens while in vacuum (described as dynamic tests). The same polymers were irradiated in vacuum and in air and the tensile strength and ultimate elongation determined in air (described as static tests). Data are given in Tables C-13 and C-14. The difference between the effects of irradiation in vacuum and in air on ultimate strength and elongation can be seen in these tables. Although not strictly comparable, the ultimate strength and elongation appear to be greater when the materials are irradiated in vacuum than when irradiated in air. With Kel-F, tensile strength is greater than that for Teflon, and neither irradiation in vacuum and nor irradiation in air seriously affects tensile properties.

It may be noted that Teflon FEP shows better radiation stability in air than does TFE, but the improvement in vacuum is minor.

The effects of radiation on Duroid 5600, a glass-fiber-reinforced Teflon, and unfilled Teflon are similar. Kynar and Tedlar both show excellent retention of tensile strength and elongation when irradiated in air and in vacuum (see Table C-15). According to Kerlin, Kynar does not have low-temperature properties as good as those of Teflon. It has, however, excellent resistance to ultraviolet radiation.

The following data show the effect of vacuum and temperature with no irradiation. At 100 C, and after 100 hours exposure to a pressure of 10^{-7} torr, the weight loss of TFE resin was found by Jolley and Reed[63] to be 0.04 per cent and that of FEP resin was 0.08 per cent. No comparable data were found for Kel-F. However, Bringer[64] compares the outgassing of Kel-F and Teflon. He states that significant weight loss for Kel-F begins to occur at about 250 C, and for Teflon at about 350 C. Outgassing rate for Teflon at 25 C is 1.6×10^{-7} torr-liters/(sec)(sq cm). This compares with a value of 3.7×10^{-7} torr-liters/(sec)(sq cm) for aluminum. The rate of outgassing of Teflon TFE and FEP decreases with time. This is also true for Kel-F. Table C-16 gives the mole per cent and identity of evolved gases for Teflon TFE at 71, 180, and 200 C.

Analyses of gases evolved from vacuum outgassing of Teflon have indicated that no degradation of Teflon resins or of their properties occurs in high-vacuum service at room temperature. Tubing of Teflon in use in the vacuum systems (10^{-6} to 5×10^{-9} torr) of the Bendix Mass Spectrometer for more than 5 years has given no mass-spectrum-analysis evidence of outgassing or breakdown of the Teflon tubing.

Buckley and Johnson[65] conducted experiments to determine the effects of vacuum on friction and wear for three polymers, including Teflon (PTFE) and Kel-F (PCFE). Both friction and wear for unfilled PTFE and PCFE in vacuum were nearly the same and were high. In general, the wear mechanism of the two polymers sliding on stainless steel surfaces was one of an abrasion process. It was found that heat generated at the sliding interface was transferred to the wear particles abraded from the polymer and adhering to the metal surface. This increased surface temperatures and caused surface degradation of the particles.

Buckley determined the influence of fillers on the wear of Teflon and Kel-F in vacuum. Fillers used for these studies included glass fiber, molybdenum disulfide, copper, silver, and graphite. The addition of glass fibers and copper powder markedly improved the friction and wear characteristics for PTFE. Molybdenum disulfide offered essentially no improvement. It is believed that improvement came as a result of dissipation of frictional heat. The effect of fillers can be seen in Figure C-3.

Decomposition products were studied for PTFE. With unfilled polymer, the principal products of decomposition were the heavier-molecular-weight fragments of the polymer unit. With glass-filled compositions, the principal decomposition product was fluorine. Copper-filled Teflon gave very small concentrations of decomposition products.

As a matter of comparison, Buckley found the friction and wear characteristics of a polyimide resin to be superior to those of Teflon TFE in vacuum. This polyimide was stable to 500 F.

Effects of Cryogenic Temperatures

The utility of Kel-F and Teflon at cryogenic temperatures has been proven in practice by their extensive use in connection with liquid oxygen (-325 F) and liquid hydrogen (-425 F)[64]. The plastics retain some degree of ductility at these temperatures. Figure C-4 shows the tensile behavior of the fluorocarbon plastics in the subzero regions. According to Vickers[66], FEP has an impact strength of 2.0 ft-lb/in. while Kel-F (medium crystallinity) has an impact value of 1.25 ft-lb/in.. Elongation of FEP is four times as great as that for Kel-F at -420 F. On the other hand, Bringer[64], measuring

thermal contraction between room temperature and liquid-oxygen or -hydrogen temperature, found that Teflon contracts roughly twice as much as Kel-F. (See Figure C-5).

Kel-F was irradiated (nuclear) at cryogenic temperatures by Yasui[13]. At radiation exposures to 2.6×10^9 ergs g^{-1}(C), the Kel-F 2-mil film was not significantly affected by irradiation in liquid nitrogen (see Figure C-6).

Effects of X-Ray and Vacuum

Low-frequency loss properties of TFE polymers are drastically affected by X-ray irradiation.[63] High-frequency loss properties are considerably less affected. Increases in dielectric constant and dissipation factor depend on the ambient oxygen concentration during exposure and recovery.

The dielectric constant and dissipation factor of Teflon FEP resins are unaffected by X-ray irradiation in vacuum for measured frequencies of 60 cps to 100 kcps.

Figure C-7 shows the effect of X-ray irradiation in air and in vacuum on dissipation factor of Teflon. Recovery characteristics are shown in Figure C-8. Changes in dielectric constant are shown in Figure C-9. In the case of FEP, dissipation factor and dielectric constant were unaffected by X-ray irradiation in vacuum (Figures C-10 and C-11), although physical and optical property changes were evident.

Measurements of electrical properties made during irradiation without removal from exposure are given by Bringer[64]. A comparison of the effects of X-ray irradiation on the dissipation factor of PTFE in both air and in vacuum are given in Figure C-12.

Effects of Ultraviolet and Vacuum

Wilcox, et al.,[58] irradiated Teflon with monchromatic light in nitrogen and with a G30T8 lamp in nitrogen and in vacuum. Data are given in Tables C-17 and C-18. The shorter wavelengths are more damaging than the longer wavelengths. Ultraviolet produces greater changes in elongation than in tensile strength; irradiation in a vacuum is approximately 14 times as severe as that in nitrogen.

Phenolic Resins

Unfilled phenolics stand fairly low in radiation resistance, 25 per cent damage being accrued at an absorbed dose of 10^9 ergs g^{-1}(C). When irradiated, they swell, become very brittle, and tend to crumble.

The addition of fillers, particularly mineral fillers, increases the stability of phenolics. Phenol-formaldehyde with asbestos filler (Haveg 41) shows excellent radiation stability, being one of the more radiation-resistant plastics. It is unaffected by a radiation exposure of 3.9×10^{10} ergs g^{-1}(C) and is damaged by 25 per cent at an exposure of 3.9×10^{11} ergs g^{-1}(C).

Phenolic laminates irradiated to an exposure of 2×10^9 ergs g^{-1}(C) at temperatures of 600, 700, 800, and 900 F showed flexural-strength values equivalent to or higher than those for laminates heated to these temperatures with no irradiation.

Redeker and Van Sickle[67] studied the effect of radiation on phenolic-model compounds in a fundamental approach to determine basic chemical reactions involved. They found that the ring-connecting methylene bridges were most easily broken when ortho to a hydroxy group. The hydrogen-oxygen bond appeared to be the most labile to radiolysis, followed closely by the carbon-oxygen bond. Their work suggested that, for radiation environmental applications, as many para links should be used in the polymer as is possible. The work also suggests that incorporation of polyhydroxybenzenes or naphthalenes into resins as a means of providing energy sinks or dissipators for the absorbed radiation is desirable.

Phosphonitrillic Chloride Polymers

Glass-cloth laminates with this resin showed excellent stability at 455 F and an exposure of 6×10^{10} ergs g^{-1}(C).

A blend of this resin and acrylonitrile showed excellent tensile strength when irradiated in air to 10^{11} ergs g^{-1}(C). However, elongation decreased to about 25 per cent when the blend was irradiated to 2.5×10^{10} ergs g^{-1}(C). Elongation decreased from 138 per cent to 94 per cent when heated to 110 F for 33 hours with no irradiation.

General Dynamics[1] developed a resin which is a derivative of phosphonitrillic chloride and which is designated as AP-Resin-XHU. The resin contains a number of unreacted polar groups (hydroxyphenyl) which can be reacted with selected curing agents and monomeric or polymeric materials containing reactive constituents. Blends of this resin with phenolics, polyesters, epoxies, polyamides, and many elastomers can be prepared. The cured resin or resin-polymer blends are reported to have flame resistance, high heat stability, high structural strength, and excellent environmental resistance.

Several of the phosphonitrillic chloride polymeric blends were irradiated both at room temperature and at elevated temperatures. A blend of the AP-Resin XHU and acrylonitrile was prepared and irradiated in air, and immersed in 5P4E polyphenyl ether (Monsanto OS-124) at temperatures ranging from 75 to 340 F. Data for this material are shown in Table 39.

In general, exposure of the blend to elevated temperatures and radiation resulted in an increase in tensile strength, elastic modulus (compression), and hardness. However, elongation decreased from 138 per cent to 94 per cent when the blend was heated to 110 F for 33 hours with no irradiation. When irradiated to 2.5×10^{10} ergs g^{-1}(C) in air at this same temperature, elongation decreased to 26 per cent. Elongation was 50 per cent when the material was immersed in the polyphenyl ether for 33 hours at 110 F with no irradiation. After irradiation to 2.1×10^{10} ergs g^{-1}(C) in the oil at 110 F (33 hours), elongation was 30 per cent. Glass-cloth laminates of this resin showed excellent radiation stability at 455 F to an exposure of 6×10^{10} ergs g^{-1}(C). Data are included in the section on laminates.

TABLE 39. PROPERTIES OF A BLEND OF AP-[illegible]N-XHU AND ACRYLONITRILE POLYMER(1)

Exposure: Gamma, ergs g^{-1}(C)	Exposure: Neutron n cm^{-2} (E > 2.9 Mev)	Medium; Temp, F; Cycle; and Time, hr	[illegible] Strength(a), psi	Ultimate Elongation(a), %	Elastic Modulus (Compression)(a), psi	Hardness(a), Shore D
Control		Air, 75, --, --	2,219/30/8	138/5.5/7	48,041/5,578/3	
Control		Air, 110, II, 33	2,242/163/5	94/5.6/5	52,467/1,162/3	65.9/1.4/5
2.5×10^{10}	2.2×10^{15}	Air, 110, II, 33	4,760/132/5	26/2.5/5	75,031/1,743/3	73.8/0.9/5
Control		Air, 150, I, 33	2,599/243/5	76/9.7/4	57,913/1,395/3	67.1/1.9/5
9.1×10^{10}	1.0×10^{16}	Air, 150, I, 33	8,067/1,230/5	1.1/1/5	124,943/2,[illegible]05/3	85.4/0.4/5
Control		Oil, 110, II, 33	2,481/55/5	50/12/5	56,614/2,105/2	68.1/0.8/5
2.1×10^{10}	2.1×10^{15}	110, II, 33	4,772/216/5	30.6/1.8/3	77,870/2,615/3	62.5/1.3/5
Control		Oil, 200, III, 33	2,824/257/5	35/5.6/5	45,253/698/2	65.6/2.1/5
7.5×10^{10}	1.0×10^{16}	Oil, 200, III, 33	6,839/555/5	3/1/4	101,659/1,162/3	73.9/2.1/5
Control		Air, 240, IV, 31(b)	6,321/1,597/2	0	133,791/6,974/3	88/1.1/5
6.8×10^{10}	5.9×10^{15}	Air, 240, IV, 31(b)	2,538/1,027/4	0	95,096/2,324/[illegible]	34.8/1.9/5
Control		Air, 310, VI, 31(b)	3,0[illegible]3/237/5	0	129,199/1,162/3	89.6/1.6/5
2.2×10^{11}	2.4×10^{16}	Air, 310, VI, 31(b)	1,798/723/[illegible]	0	125,920/11,621/3	90.8/[illegible].6/4
Control		Oil, 270, V, 31(b)	2,490/467/4	0	51,467/2,350/3	76.9/1.6/4
5.2×10^{10}	5.1×10^{15}	Oil, 270, V, 31(b)	5,623/322/5	8.4/1.3/5	49,181/2,324/3	69.7/2/5
Control		Oil, 340, VII, 31(b)	2,720/1,016/3	0	59,353/2,905/3	79.0/2.1/5
1.7×10^{11}	2.4×10^{16}	Oil, 340, VII, 31(b)	3,962/668/5	0	104,671/3,487/3	78.9/2.1/5

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of an individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Tensile specimens sagged and bent during the 14-day storage at 350 F; consequently, the data for these samples are of doubtful validity.

Polyacetal

No radiation data were found for this polymer. Podlaseck and Suhorsky[4] gave the equilibrium-weight-loss rate for Delrin 500 and Delrin 507 (carbon-black-filled 500); see Table C-4 in Appendix C. Values were also given by Fulk[17] in Table B-70 (Appendix B). These were the only data found for this polymer.

Polyamide (Nylon)

Nylon, tested in sheet form, reaches threshold damage at an absorbed radiation of 8.6×10^7 ergs g^{-1}(C) and 25 per cent damage at 4.7×10^8 ergs g^{-1}(C). Its tensile strength increases with radiation, reaching 25 per cent increase at 10^{11} ergs g^{-1}(C).

Nylon fiber was reported to have lost more than 50 per cent of its original strength at an exposure of 8.5×10^8 ergs g^{-1}(C).

The service life of nylon in air can be increased by the use of antirads or antioidants.

Nylon shows good heat stability in vacuum.

Koehler and Pefhany[28] reported that nylon (Zytel 33), when irradiated to 2×10^{10} ergs g^{-1}(C) in a dry atmosphere was satisfactory and could be used in a gaging system for reactor pressure tubes designed to measure surface defects during periods of reactor shutdown. A nylon ring used in this equipment was also satisfactory, although its color changed to a brown.

Although the following data are not concerned with the effects of nuclear radiation, they are of interest with respect to space applications. These include weight-loss data in vacuum, and the effect of thermal radiation, ultraviolet, and the effect of fillers on lubrication properties of nylon in vacuum.

The stability of nylon in space environments will vary according to the processing of the material. However, in general, nylon is useful under space conditions. Podlaseck and Suhorsky[4] give the equilibrium-weight-loss rate as follows:

Material	Temperature, C	Pressure, torr	Equilibrium-Weight-Loss Rate, g/(sq cm)(sec) x 10^{10}
Nylon (Zytel 105) (carbon-black-filled 101)	50	5×10^{-6}	0.33
	100	5×10^{-6}	3.3
Nylon (Zytel 31) (electrical grade nylon)	50	5×10^{-6}	0.89
	100	5×10^{-6}	3.3
Nylon (Zytel 101) (standard grade nylon)	50	5×10^{-6}	0.94
	100	5×10^{-6}	4.2

Jaffe and Rittenhouse[51] give the temperature for 10 per cent weight loss per year for nylon in high vacuum as 30 to 210 C (80 to 410 F). He indicates nylons show high decomposition rates in vacuum. However, Riehl[57] states that nylon lost 0.05 per cent weight on desiccation and 0.01 per cent more on vacuum exposure. It returned to its original weight (<0.001 per cent difference) on re-exposure to air. He thus claims that vacuum exposure served only to provide more drastic desiccation.

Boundy[31] reported the weight loss of Nylon-101 in vacuum (10^{-6} torr) at 75, 150, and 300 F. Even at 300 F, the weight loss was only about 0.63 per cent (see Figure 20).

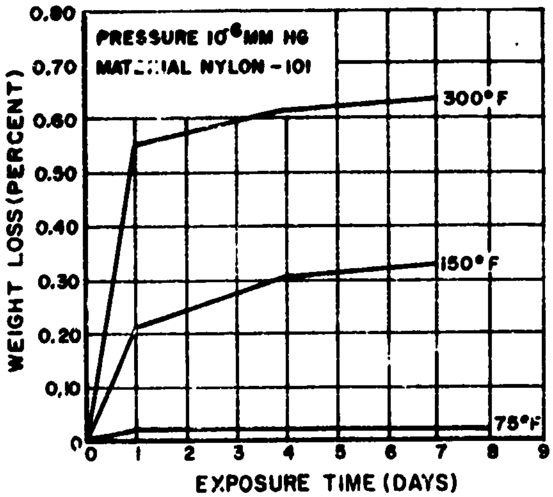


FIGURE 20. PER CENT WEIGHT LOSS VERSUS TIME AT 10^{-6} TORR AND VARIOUS TEMPERATURES FOR NYLON[31]

Hargreaves[68] exposed Nylon 66 to thermal radiation in vacuum. Results are given in Table C-19 in Appendix C. He found that heat and vacuum (10^{-5} torr) decreased the over-all transmission in the 220 to 330 mμ range. The effect of heat and vacuum is, first, to induce crosslinking but later, to induce chain scission. However, less than 2 per cent of the chemical structures are affected. Thermal radiation in the range of 180 to 275 C has no significant effect on the melting point. Specimens heated to 275 C darkened, fused, and were insoluble in a calcium chloride-methyl alcohol solvent. The fiber was brittle and useless as such, but the basic structure was unchanged.

Wilcox, et al.,[58] found that changes in tensile strength of nylon were produced twice as fast by ultraviolet in nitrogen as in a vacuum (see Tables C-20 and C-21). Blackmon[5] states that nylon irradiated in a vacuum (10^{-7} torr) with ultraviolet for 91 hours shows very slight discoloration, and retains good tear and tensile strengths.

Because of its stability in vacuum, and because of its use as bearings which need no lubrication, nylon has been examined for use as a dry lubricant for space applications. Bowen[69] determined the wear of nylon materials containing various fillers. Tests were run at rubbing velocities of 460 and 230 ft/min. at temperatures of 86 F and 160 F. The load on the test block was 3 pounds (150 psi for a 2-mm scar width). The atmosphere nitrogen. The nylon which did not contain a lubricant filler was unsatisfactory; it

was considered better with 40 per cent MoS_2 filler (Nylasint 144) than with 70 per cent carbon-graphite (even though the friction is higher because of the expected poor lubricating qualities of graphite in a space environment). Outgassing tests, however, indicated that Teflon would be more acceptable than the nylon.

Polycarbonates

Lexan retained strength and toughness after an exposure of 8×10^9 ergs g^{-1}(C), but these properties decreased rapidly after 9×10^9 ergs g^{-1}(C). It can probably be considered as useful to 10^{10} ergs g^{-1}(C).

Radiation resistance of Lexan in vacuum is only slightly better than that in air.

At 300 F, polycarbonates are superior to nylon with respect to vacuum-thermal stability.

Polycarbonates have excellent impact strength and dimensional stability and resist thermal-oxidative degradation up to 150 C. They are reasonably good with respect to radiation resistance.[70] Lexan (General Electric polycarbonate) retained most of its original strength and toughness after irradiation to 8×10^9 ergs g^{-1} (C). However, in another investigation, a sample irradiated in air[11] was found to have lost all tensile strength at an exposure of 2.9×10^{10} ergs g^{-1} (C). Oxidation is relatively minor below an exposure of 8.8×10^9 ergs g^{-1} (C). Merlon polycarbonate irradiated at 75 F to a dose of 3.5×10^{10} ergs g^{-1} (C) in air showed no appreciable change in hardness. Its ultimate strength decreased from 8590 psi to 2070 psi. At 10^{10} ergs g^{-1} (C), elongation decreased from 104 per cent to 54 per cent. At an exposure of 2×10^{11} ergs g^{-1} (C), the material was too brittle to determine these properties. Thus it would appear that these materials would be satisfactory to an exposure of about 10^{10} ergs g^{-1} (C), but that properties begin to fall off considerably above that exposure.

Samples irradiated in vacuum were very brittle after an exposure of 8.8×10^{10} ergs g^{-1} (C). Giberson[71] states that it is possible that less than this exposure dose would be required to obtain this degradation. Evidently the radiation stability of this polymer in vacuum is just slightly better than its stability in air. Giberson concluded that degradation of polycarbonates in an irradiation field occurs by a chain-scission mechanism.

Moulton and associates[72] studying the effect of X-ray irradiation on the optical, electron paramagnetic resonance, and diffusion properties of Lexan found that X-ray irradiation induced cross linking rather than degradation of the polymer.

Jaffe and Rittenhouse[51] give 180 C (350 F) as the temperature for 10 per cent weight loss per year in vacuum, but indicate that the basis for this value is not too reliable. Gloria, et al.,[61] tested Lexan in vacuum and found its initial weight loss to be similar to that of Teflon. There was no apparent change in physical appearance up to its heat-distortion temperature. The initial rates of weight loss of Lexan, epoxy, nylon-phenolic, and silica-phenolic were found to increase significantly with decreasing material thickness, indicating that the diffusion of the reaction products through the bulk of the material was a controlling factor in the weight-loss process of these materials.

Boundy[31] determined the weight loss of polycarbonate resin in a vacuum (10^{-6} torr) at 75, 150, and 300 F. Data are shown in Figure 21. At the higher temperatures, polycarbonate is markedly superior to nylon as far as vacuum-thermal stability is concerned.

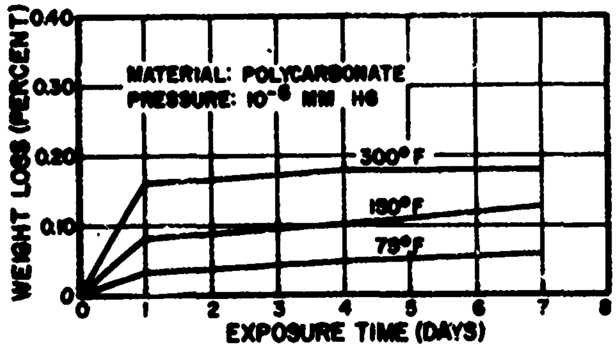


FIGURE 21. PER CENT WEIGHT LOSS VERSUS TIME AT 10^{-6} TORR AND VARIOUS TEMPERATURES FOR POLYCARBONATE[31]

Polyesters

Unfilled polyesters have poor radiation stability, hardening and developing small cracks under irradiation. Their properties begin to change at approximately 10^7 to 10^8 ergs g^{-1} (C).

Oriented films appear to have greater stability than the random polymer. Mylar (polyethylene terephthalate) has been reported as reaching threshold damage at an exposure of 4.4×10^8 ergs g^{-1} (C) and 25 per cent damage at about 8.7×10^9 ergs g^{-1} (C).

Irradiation of Mylar in vacuum to 8.7×10^9 ergs g^{-1} (C) produced the same damage as 4.4×10^9 ergs g^{-1} (C) in air.

Mylar is unaffected during thermal aging up to 200 C (392 F) by irradiation, except at levels above 10^{10} ergs g^{-1} (C).

When exposed to ultraviolet in a vacuum, Mylar decreases in tensile strength and elongation.

Polyesters are used in laminates and in coatings and are covered in those sections of this report. Matacek[73] reported on work in which cumulative stepwise weight losses were obtained. One of the resins tested was unfilled Paraplex P-43 polyester. After exposure to 400 F and a vacuum of 4×10^{-5} torr for 24 hours, the polyester had lost 20 per cent in weight, and testing of this material was discontinued. Luperco ATC had been used as the catalyst, and it has been shown that benzoyl peroxide can cause depolymerization under proper conditions. This and the fact that no filler was present may have been part of the reason for the high weight loss.

Polyethylene Terephthalate (Mylar)

Kerlin and Smith[7] irradiated Mylar A and Mylar C in air and in vacuum. Although earlier tests had shown irradiation to be less damaging in vacuum than in air (particularly with a 3-mil film), later results (see Table C-22 in Appendix C) would indicate that there is little difference between irradiation in air and in vacuum.

Yasui[13] irradiated Mylar film, aluminized Mylar, and several Mylar laminates at cryogenic temperatures. There were no significant effects on these materials. Data are shown in Figures C-13 to C-15.

Mylar capacitors were tested for performance characteristics in a nuclear-radiation field at Bendix Systems Division of Bendix Corporation[38] and at Litton Industries[27]. The results of the tests at Bendix indicated that film capacitors were well suited for use in radiation environments, at least up to an exposure of approximately 10^{10} ergs g^{-1} (C) (about 10^{15} nvt). Capacitance and dissipation factor were little affected by irradiation. Leakage resistance was reduced during irradiation whenever the reactor was at power, but no permanent changes in leakage resistance were observed. The capacitors became slightly radioactive during the irradiation; this activity was sufficiently small to indicate that these capacitors do not present a serious handling problem when used in radiation environments with thermal-neutron shielding. Litton Industries, on the other hand, found that the Mylar film-foil capacitors suffered permanent degradation in insulation resistance, i.e., their insulation resistance showed negligible recovery 24 hours after removal from the environment. The exposure was 10^{11} ergs g^{-1} (C) (10^{16} n cm^{-2}, $E_n > 2.9$ Mev). Also, it was shown that the electrical properties of capacitors made from the same dielectric material but by different manufacturers differed considerably from one another.

Mylar has been found to have extremely low outgassing rates at room temperature, similar in this respect to fluorocarbons and silicones. Riehl[57] tested the stability of Mylar under high vacuum (Table C-23). Plain and aluminum-vapor-coated Mylar films were exposed to various temperatures at a pressure of 10^{-5} to 10^{-6} torr for a duration of 72 hours. It was found that Mylar, with or without an aluminum coating, exhibited only a slight loss in flexibility after exposure to the test conditions at room temperature. At 100 C, under the same conditions of pressure and time, weight losses were appreciable. Both coated and uncoated films warped and/or wrinkled, and all samples suffered appreciable losses in flexibility. Similar tests at 150 C produced increased weight losses and distortion.

Effects of Ultraviolet Radiation

Versluys, et al.,[55] subjected Mylar to ultraviolet radiation at 10^{-8} torr to a dose of 50 hours of insolation in the 1300 to 1850 A band and 565 hours in the 1100 to 1300 band. Weight loss was 0.2 ± 0.2 per cent. Vacuum exposure alone gave 0.3 ± 0.3 per cent. The released gas was analyzed by means of a mass spectrometer and found to be nitrogen, which was assumed to be adsorbed to the Mylar

Table C-24 shows the effect of vacuum and combined vacuum and ultraviolet on Mylar aluminized on one side, as determined by Snyder[47]. Ultraviolet (770 hours' exposure) caused a decrease of 43 per cent in tensile strength and a decrease of

88 per cent in ultimate elongation. Table C-25 shows the effect of ultraviolet and vacuum on the tensile strength at butt-seamed areas using Mylar tape with various adhesives.

Wilcox, et al.,[58] irradiated Mylar in nitrogen and in vacuum with ultraviolet (Tables C-20 and C-21). Elongation decreased faster for samples irradiated in nitrogen than it did for samples irradiated in a vacuum. Also, tensile strength was less affected in vacuum than in nitrogen.

Blackmon, et al.,[5] also reported the effects of ultraviolet and vacuum on Mylar, both metalized and nonmetalized. After 91 hours at 80 F and 10^{-7} torr, there was no change in the aluminized Mylar. The uncoated 5-mil material turned brown and disintegrated on handling.

In summary, Mylar has low outgassing in a vacuum at room temperature. However, elevated temperatures and, particularly, ultraviolet adversely affect weight loss and tensile properties.

Polyethylene

Polyethylene is unaffected by radiation to an absorbed radiation of 1.9×10^9 ergs g^{-1} (C), and accrues 25 per cent damage at 9.3×10^9 ergs g^{-1} (C). Tensile strength increases at first, but at approximately 1.1×10^{10} ergs g^{-1} (C), it begins to decrease, and is 25 per cent lower than the initial value at approximately 10^{12} ergs g^{-1} (C).

Polyethylene is subject to oxidation when irradiated. As a result it is more stable in vacuum than in air.

Kerlin and Smith[7] found that Marlex 6002, a high-density polyethylene, irradiated in air to an exposure of 10^9 ergs g^{-1} (C) decreased in elongation from 907 per cent to 14 per cent. However, in vacuum, the decrease was only to 675 per cent. Tensile strength increased both in air and in vacuum but the increase was slightly higher in vacuum. Data are shown in Appendix C, Table C-26.

Gray, et al.,[8] found polyethylene, along with silicone rubber, to be the most effective seal for reciprocating service in a vacuum environment. Leak rates were very low (5×10^{-5} standard cubic centimeters of helium gas per second) after test durations of 30 minutes. Gray suggests that a dry lubricant such as molybdenum disulfide should be used to obtain good results. Polyethylene and Vinylite (polyvinyl chloride), in an O-ring configuration, were also effective in static sealing applications. They were not appreciably affected by 2-week vacuum exposures at 1×10^{-7} torr.

Jaffe and Rittenhouse[51] list polyethylene and polypropylene as exhibiting good-to-excellent behavior in high vacuum. Fulk[17] determined the equilibrium-weight-loss rate for irradiated polyolefins (probably polyethylene). Values are given in Table B-70 (Appendix B).

Versluys, et al.,[55] studied the effect of ultraviolet on polyethylene and noted that weight loss in vacuum with no irradiation was 0.3 ± 0.2 per cent, but when irradiated, no weight loss was observed. The exposure did not change the appearance of the

polymer. The exposure of the sample was equivalent to 28 hours of insolation in the 1300 to 1850 A band and 1975 hours in the 1100-1300 A band.

Wilcox, et al.,[58] irradiated polyethylene with ultraviolet light in nitrogen and in vacuum. A wavelength of 244 mμ was more damaging than the 314 or 369 mμ. Also, changes in tensile strength were produced about three times faster in nitrogen than in a vacuum (see Table C-20).

Polypropylene

Polypropylene has been found to be inferior to polyethylene in radiation resistance. At an exposure of 8.7×10^9 ergs g^{-1} (C), it has become brittle and lost all of its elongation and most of its tensile strength.

Sauer[74] in his studies of the effects of gamma irradiation on the dynamic mechanical properties of various polymers has shown that crosslinking efficiencies of polypropylene are from one and one-half to two times greater for quenched isotactic polypropylene samples than for annealed specimens.

Polyallomers

Irradiated to an exposure of 9.4×10^{10} ergs g^{-1} (C) at 75 F, a propylene-ethylene polyallomer retained only 25 per cent of its tensile strength. Above 2.8×10^{10} ergs g^{-1} (C), hardness decreased and the material became very tacky. Elongation decreased considerably between 3×10^8 ergs g^{-1} (C) and 10^9 ergs g^{-1} (C).

These materials are defined as crystalline thermoplastic polymers produced from two or more different monomers. These are not copolymers in the usual sense, nor are they blends, but are more like block polymers. One of the more interesting of these is the propylene-ethylene polyallomer. This polymer exhibits many of the best properties of both high-density polyethylene and crystalline polypropylene. Propylene-ethylene polyallomers are superior to the linear polyethylene in flow characteristics, softening point, hardness, stress-crack resistance, and mold shrinkage. They overcome the most serious property deficiencies of crystalline polypropylene, offering lower brittleness temperatures, higher impact strengths, and less notch sensitivity. However, the polyallomers retain the desirable built-in hinge effect that is exhibited by crystalline polypropylene. Polyallomers in many respects are as easy to mold as crystalline polypropylene and easier to mold than linear polyethylene.

In wire covering and cable jacketing, the propylene-ethylene polyallomers offer a good balance of impact strength, elongation, stress-crack resistance, and low-temperature toughness while retaining the desirable electrical properties of the other polyolefins.

Lewis[15] irradiated a propylene-ethylene polyallomer at room temperature and at temperatures of 205 to 250 F. When the material was irradiated to 9.4×10^{10} ergs g^{-1} (C) at 75 F, tensile strength decreased from 4380 psi to 1100 psi. Above 2.8×10^{10} ergs g^{-1} (C), hardness decreased and the material became very tacky. Elongation

decreased considerably between 3 x 10^8 and 10^9 ergs g^{-1} (C). At 250 F, after irradiation to an exposure of 2.4 x 10^{10} ergs g^{-1} (C), the specimens were stuck to the foil wrapper and tore easily. At 200 F, tensile strength decreased from 4390 psi to 1300 psi at an exposure of 2.9 x 10^9 ergs g^{-1} (C) while elongation decreased from 688 per cent to 34 per cent at an exposure of 9.7 x 10^8 ergs g^{-1} (C). Data are shown in Table 40.

TABLE 40. SUMMARY OF EFFECTS OF IRRADIATION AT TWO TEMPERATURES ON PROPYLENE-ETHYLENE POLYALLOMER (CRYSTALLINE POLYMER) (EASTMAN)[(a)(15)]

Gamma Exposure, ergs g^{-1} (C)	Temp, F	Hardness[(b)], Shore D	Yield Strength[(a)], psi	Tensile Strength[(a)], psi	Ultimate Elongation[(a)], %
0	75	63.9	3280/123/15	4380/482/15	770/60/15
3.2 x 10^8	80	67.1	3460/84/15	4050/493/15	771/63/15
1.2 x 10^9	80	69.5		3470/171/15	20/5.7/15
2.7 x 10^9	75	70.3		2850/79/14	5
8.3 x 10^9	75	71.6		2130/122/15	2-3
2.8 x 10^{10}	75	64.7		2880/100/15	22/5/15
9.4 x 10^{10}	75	35.4[(c)]		1100/75/13	30/9.0/13
0	250	69.7	3300/44/15	4390/196/15	688/40/15
2.7 x 10^8	205	68.9	3330/62/14	3100/469/15	687/22/11
9.7 x 10^8	205	68.7		3360/93/15	34/[illegible]/15
2.9 x 10^9	230	69.4		1300/135/14	Small
1.1 x 10^{10}	235	63.1		1400/135/15	5
2.4 x 10^{10}	245	(d)			(e)
8.0 x 10^{10}	248	(d)			(e)

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of an individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Average of 30 measurements.

(c) Very tacky.

(d) Too tacky to measure.

(e) Specimens were stuck to foil wrapper and tore easily.

Polyimide

Nomex yarn (Fiber HT-1) was reported to be unaffected to an exposure of 3.3 x 10^{10} ergs g^{-1} (C).

At 500 F and 1.4 x 10^9 ergs g^{-1} (C) gamma exposure, the yarn retained 45 per cent of its elongation and 62 per cent of its tensile strength.

Polyimide fiber [HT-1 (Du Pont Nomex yarn)] has approximately the same strength characteristics as nylon, with greatly increased resistance to heat and gamma irradiation.[(75)] There are no melt-flow characteristics below 750 F. It does not have the objectionable melt-drop characteristics of nylon. Its strength is unaffected by exposure to 3.3 x 10^{10} ergs g^{-1} (C) gamma irradiation. No practical solvents for this yarn are known at present.

McGrath[76] irradiated Nomex yarns at 100, 400, 500, and 600 F. These were then oven aged for 2 hours. The natural yarn and two-color sealed yarns were irradiated, the colors used being International Orange and Olive Green. Strength and elongation properties are given in Tables C-27 through C-34 in Appendix C. It may be noted in Tables C-30 and C-33 that the natural yarn when irradiated at 500 F to an exposure of 1.4×10^9 ergs g^{-1} (C) retained 45 per cent of its elongation and 62 per cent of its strength. Variations between the dyed yarns and the natural yarns were believed to be due to a variation in the yarns and twist of the yarns rather than to the color process.

Stephenson, et al.,[77] irradiated polyimide fibers [HT-1 (Du Pont)], polybenzimidazole, and thiazole polymer (Southern Research Institute). During ultraviolet irradiation of HT-1, no volatile products were detected. No differences in degradation were noted between irradiations in air, nitrogen, or vacuum (10^{-3} and 10^{-6} torr) (see Figure C-16). Exposure to energy at a wavelength of 369 mμ caused greater deterioration than that at 244 or 314 mμ. Irradiation of polybenzimidazole fibers with 253.7 mμ light from the G30T8 lamp produced greater deterioration of tensile properties in oxygen than in nitrogen or in vacuum (see Figure C-17). Irradiation in nitrogen produced effects in elongation that were intermediate between those produced by irradiation in oxygen and in vacuum.

Fibers of a thiazole polymer appeared not to be affected differently in nitrogen, oxygen, and vacuum. As shown in Figure C-18, no loss of tensile strength due to X-ray irradiation was apparent, but some decrease in elongation was noted.

Du Pont "H" film, considered for use as a hydrogen barrier, was irradiated (nuclear) while immersed in liquid nitrogen.[13] Tensile and tear strengths of 2-mil sheet were similar to those of 2-mil Mylar. These properties were not significantly affected by exposure to 2×10^9 ergs g^{-1} (C). Data are shown in Figure C-19. Radiation did not affect hydrogen permeability.

Mathes[78] evaluated wire insulation for cryogenic applications after thermal aging in air and vacuum and after moisture exposure. Among the materials examined were HML (a heavy aromatic polyimide enamel), HML asbestos [a polyimide solution (ML) coated, felted asbestos], and Glass/ML [a polyimide solution (Du Pont ML) coated glass fiber insulation]. These were also examined at cryogenic temperatures. The advantages of the ML material is that it has the greatest flexibility at cryogenic temperatures, excellent thermal stability, mechanical toughness, and no measurable thermal cut-through. Its disadvantages are that it is available only as a relatively thin film coating and it is somewhat sensitive to moisture. Evaluation of coated wires consisted of repeated mandrel flexibility tests in liquid hydrogen. Figures C-20 and C-21 give a comparison of breakdown voltage in air, vacuum, and liquid nitrogen. Voltage breakdown of HML is not significantly affected by thermal aging, even at 250 C.

Buckley and Johnson[65] investigated the usefulness of polyimide resins as lubricants in the space environment. To determine relative stability in a vacuum, some evaporation studies were conducted in vacuum to 10^{-8} torr and at ambient temperatures to 875 F. Data are shown in Figure C-22. Evaporation rate was less than 10^{-10} g/(sq cm)(sec) from ambient temperatures to 500 F. Above 500 F, the polyimide began to lose weight at an appreciable rate, and at 875 F, the rate was too high to follow with the recorder.

Friction and wear studies were conducted in vacuum (10^9 torr) with polyimides sliding both on metals and on themselves. Although friction for polyimides on Type 440 C stainless steel was relatively low, wear to the polyimide rider was somewhat high (Figure C-23). However, the wear for the polyimide is only one-fifteenth that obtained with Teflon, and the friction is also lower.

With polyimide sliding on itself, the friction was higher than with polyimide on stainless steel, but wear was 1/500th that of the polyimide on metal (Figure C-24).

A 15 per cent graphite-filled polyimide composition was also examined in friction and wear studies. The presence of graphite in the polyimide did not improve its lubricating characteristics; relatively high friction and wear were obtained.

Suess and Neff(79) examined six insulated wires for use in a space environment. One of these was "Suroc" FEP w/corona etched, bonded "ML polyimide" manufactured by Supernant Wires; another was Teflon FEP and "H" film laminated into tape and helically wrapped. On the basis of weight loss, dissipation factor, dielectric constant, capacitance, and abrasion resistance, the best selection appeared to be an extruded Teflon and the FEP-ML coated wire. However, he found that the FEP-ML coating was quite sensitive to ultraviolet degradation.

Polystyrene

Polystyrene is one of the most radiation resistant of all polymers. It exhibits threshold degradation at an exposure of 10^{10} ergs g^{-1} (C) and 25 per cent damage at greater than 10^{11} ergs g^{-1} (C).

Exposures of 10^{12} ergs g^{-1} (C) are required in a vacuum to produce significant change in its infrared spectra.

Polystyrene film was not affected at 75 F by an exposure of 8 x 10^9 ergs g^{-1} (C). At 9.4 x 10^{10} ergs g^{-1} (C), it retained 54 per cent of its initial tensile strength.

Lewis(15) irradiated polystyrene film at 75 F to an exposure of 9.4 x 10^{10} ergs g^{-1} (C). Tensile strength did not change appreciably until after an exposure of 8 x 10^9 ergs g^{-1} (C). At an exposure of 9.4 x 10^{10} ergs g^{-1} (C), the polystyrene retained 54 per cent of its initial tensile strength. Ultimate elongation decreased from 6.5 per cent to 3.2 per cent (see Table 41).

TABLE 41. EFFECT OF IRRADIATION ON TENSILE PROPERTIES OF POLYSTYRENE FILM(15)

Gamma Exposure, ergs g^{-1} (C)	Temp, F	Tensile Strength(a), psi	Ultimate Elongation(a), %
0	75	1120/40/15	6.5/0.29/15
3.2 x 10^8	75	1130/32/14	6.8/0.44/14
1.2 x 10^9	75	1090/28/15	6.3/0.46/15
2.7 x 10^9	75	1090/37/15	6.4/0.32/15
8.3 x 10^9	75	1080/45/15	6.3/0.40/15
2.8 x 10^{10}	75	976/102/15	5.3/0.49/15
9.4 x 10^{10}	75	512/52/15	3.2/0.25/15

(a) Data are given as $\overline{x}$/S.D./n, where $\overline{x}$ = average value, S.D. = standard deviation of an individual observation estimated from the range, and n = number of specimens used in calculating $\overline{x}$ and S.D.

Riehl[57] found that high-impact polystyrene lost only moisture in vacuum at room temperature and at 50 C. At 100 C, sustained weight loss occurred.

Versluys, et al.,[55] tested Trycite-1000 film (Dow polystyrene film - 1 mil) for weight loss after exposure to vacuum and to X-ray in vacuum. Weight loss in both cases was 0.1 per cent. The exposure did not cause a change in appearance. Insolation was for 128 hours for the 1300 to 1850 A band and 3500 hours for 1100 to 1300 A band.

Blackmon, et al., and Clauss[5,39] determined the effect of elevated temperature on plastic potting compounds. Eccoseal HI-Q, a polystyrene-solvent system, showed no visible effects after room-temperature vacuum exposure, but vigorous bubbling and outgassing resulted at 170 F in vacuum (10^{-7} torr). This was probably due to the trapped solvent.

Polyurethane

A polyurethane foam sandwich sample showed no reduction in mechanical properties up to 10^{11} ergs g^{-1} (C), the largest exposure to which the sample was subjected.

The compressive strength of a polyurethane thermal insulation appeared higher when irradiated in vacuum than when irradiated in air.

Kerlin and Smith[7] irradiated two polyurethane thermal-insulation materials in air and in vacuum. These were tested for compression strength. Irradiation to an exposure of 5×10^{8} to 10^{9} ergs g^{-1} (C) did not seriously affect this property. Compressive strength when tested in a vacuum appeared somewhat higher. Data are given in Table C-35, Appendix C.

The effect of nuclear-radiation exposure at cryogenic temperatures was examined on four polyurethane foams by Yasui.[13] The materials were Magnolia Foam, Marfoam, CPR 20-3 Foam, and Douglas Insulation. Data are given in Figures C-25 to C-28. There was no statistically significant difference between the controls and irradiated specimens of Magnolia Foam or Marfoam. CPR-20-3 increased about 39 per cent in shear strength in the anisotropic direction. Yasui attributes this to the fact that the individual cells within the foam were elongated in this direction and were mutually parallel. Radiation did not affect compressive properties.

Matacek[80] investigated the effect of humidity during cure on a polyurethane resin (Multron R-10/Mondur C) with respect to weight loss in vacuum. The materials cured at high humidity had a greater weight loss when exposed to elevated temperatures in vacuum than those cured at low humidity.

Clauss and Blackmon, et al.,[5,39] in their investigations of encapsulating materials, found PRC 1535A/B satisfactory after vacuum-temperature exposure. The material was not irradiated, but on the basis of its radiation stability in air, it would be anticipated as being satisfactory in the combined radiation-vacuum-temperature environment. They stated that it had a high mold shrinkage and turned slightly brown after 170 F aging. They rated it as appearing satisfactory as an encapsulant.

Poly n-Vinyl Carbazole

There was no appreciable change when Grinlan F plastic was irradiated to 2 x 10^{11} ergs g^{-1} (C) at room temperature.

Grinlan F plastic (poly n-vinyl carbazole)[15] showed extremely good radiation resistance at room temperature. When the material was irradiated to an exposure of 2 x 10^{11} ergs g^{-1} (C), there was no appreciable change in hardness, specific gravity, or tensile strength. Values for the last property were 2900 psi and 2590 psi before and after irradiation, respectively. Data are shown in Table 42.

TABLE 42. SUMMARY OF EFFECTS OF IRRADIATION ON GRINLAN F (POLY N-VINYL CARBAZOLE) PLASTIC[15]

Gamma Exposure, ergs g^{-1} (C)	Temp, F	Specific Gravity at 25 C	Hardness[a], Shore D	Tensile Strength[b], psi
0	75	1.185	91.5	2900/206/15
4.9 x 10^8	75	1.187	88.8	2630/448/14
1.8 x 10^9	75	1.187	89.8	2700/421/[illegible]
3.6 x 10^9	50	1.186	88.2	2690/371/15
[illegible] x 10^{10}	50	1.188	89.4	2660/324/15
3.5 x 10^{10}	50	1.188	88.9	2830/132/14
2.0 x 10^{11}	70	1.188	91.3	2590/274/14

(a) Average of 30 measurements.

(b) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

Silicones

Silicone resins, used for laminates, coatings, and insulating materials, are not seriously degraded at exposures to 10^9 or 10^{10} ergs g^{-1} (C) and, with the proper filler, are satisfactory to 10^{11} ergs g^{-1} (C).

The stability of silicones to radiation depends upon their structure. The presence of phenyl groups in the silicone chain increases radiation stability, while the presence of methyl groups increases flexibility.

Dexter and Curtindale[36] investigated the combined effects of temperature and radiation on silicones. Samples were irradiated at temperatures of 150 and 200 C. Electrical and physical properties were measured 24 hours or longer after removal from the radiation source. Since time constants of the decay of transient effects on silicones are less than 10 minutes and stable properties are attained within 1 hour, transient effects were not considered in this work. Electrical properties were measured at room temperature and in some cases at elevated temperatures. Materials evaluated included:

Silicone Fluids

Dow Corning 200 Fluid, 20 centistokes	Dimethylpolysiloxane
Dow Corning 200 Fluid, 1000 centistokes	Dimethylpolysiloxane
Dow Corning 510 Fluid	Phenylmethylpolysiloxane
Dow Corning 710 Fluid	Phenylmethylpolysiloxane
Sylgard 51 Dielectric Gel	Dimethylpolysiloxane

Silicone Compounds

Dow Corning 4 Compound	Silica-filled dimethyl silicone
Dow Corning 5 Compound	Silica-filled phenylmethyl silicone

Silicone Elastomer

Silastic 1602

Silicone Resins

Dow Corning R-7521	Solventless resin	Silica sand or zirconium orthosilicate filled
Dow Corning 980	Impregnating varnish	Glass cloth filled
Dow Corning Sylgard 182	Solventless resin	No filler

In general the effect of the elevated temperature was to decrease the radiation resistance of the material by approximately 50 per cent. Electrical properties of the silicone fluids did not change significantly during exposure to radiation and high temperature. (150 to 200 C). Their usefulness is limited by their increase in viscosity. Effects of temperature and radiation on electrical and physical properties of silicone fluids are shown in Figures C-29 and C-30 in Appendix C.

Silicone insulating compounds are used as sealing materials in electronic apparatus and as a water-repellant surface coating for ceramic insulators. The phenylmethyl based compounds gelled after a radiation exposure of 4×10^9 ergs g^{-1} (C) [40 megarads] at room temperature, 2×10^9 ergs g^{-1} (C) at 150 C, or 10^9 ergs g^{-1} (C) at 200 C. The expected life of a dimethyl based compound is about one-half of this. Electrically, neither compound was significantly affected by radiation doses in excess of the gelation dose. Data are shown in Figures C-31 and C-32.

Silastic 1602 is discussed in the section on silicone elastomers, while R-7521 is included in the discussion on potting compounds. Data on the effects of temperature and radiation on the various silicones are shown graphically in Figures C-29 to C-37.

Silicone resins are also used in laminates, coatings and seals. As such, they are discussed under those headings in this report. According to Jaffe and Rittenhouse(51), the temperature for 10 per cent weight loss per year in vacuum for methyl phenyl silicone resins is greater than 380 C (710 F). Jaffe lists silicone resins along with Teflon, polyethylene, polypropylene, and Mylar as showing good-to-excellent behavior in high vacuum. Podlaseck and Suhorsky(4) show the equilibrium weight loss for silicones at elevated temperatures (see Table C-4). At atmospheric pressure, these losses appear high, but in a vacuum they are considerably lower and within a usable range.

Vinyl Polymers

Polyvinyl chloride (PVC) is equivalent to polyethylene in its radiation stability. Its properties begin to change at a radiation exposure of 1.9×10^{9} ergs g^{-1} (C), while it is damaged by 25 per cent at an exposure of 1.1×10^{10} ergs g^{-1} (C).

Tensile strength of PVC is not affected until it is given a radiation dose higher than that which affects polyethylene. However the tensile strength of PVC decreases more rapidly than that of polyethylene, whereas its elongation decreases less rapidly than that of polyethylene.

The liberation of hydrogen chloride when PVC is irradiated makes this material unsuitable for many applications in a nuclear environment.

Aitken and associates(81) investigated the effect of plasticizer, filler, and stabilizer on the radiation resistance of polyvinyl chloride. Two levels of radiation exposure were used, 10^{10} ergs g^{-1} (C) and 2×10^{10} ergs g^{-1} (C). The polymer used for this study was Geon 101. Fillers were carbon black (Vulcan black XXX), precipitated whiting (97 per cent $CaCO_3$, 99.98 per cent passes 200 mesh), china clay (Stockalite), anatase titanium dioxide (Tiona G), and rutile titanium dioxide (Runa R. G.). Plasticizers studied were tritolyl phosphate (TTP), Reoplex 100 (a sebacate polyester used in formulations which require maximum extraction resistance), and dioctyl sebacate. Stabilizers included white lead paste ground in DOP (dioctyl phthalate) in a ratio of 7:1 by weight and used at a level of 8 parts per hundred parts of polymer, and "Stabilizer Mixture", a nonlead mixture normally designed to confer thermal stability to PVC formulations. This mixture consisted of:

Material	Parts by Weight
Organic tin (Stanclere DBTL)	1.2
Organic cadmium (Ferroclere 202)	0.4
Epoxidized oil (Ferroclere 900)	1.0

The mixture was used at a level of 2.6 parts per hundred parts of polymer.

Plasticizer-polymer ratios of 35/65 and 45/55 by weight were used. Levels of filler were 10 per cent and 20 per cent by weight of the total (plasticizer plus polymer).

None of the interactions reached the level of significance in changes of tensile strength. However, on the basis of elongation and tensile values before and after radiation, the following conclusions were reached:

(1) **Plasticizer Type and Content**

Tritolyl phosphate showed the least degradation; the average drop in elongation was only 8 per cent after 1×10^{10} ergs g^{-1} (C) and 25 per cent after 2×10^{10} ergs g^{-1} (C). Reoplex 100 lost 36 per cent and 59 per cent, respectively, under the same radiation exposures. Only dioxtyl sebacate (DOS) showed a decrease in tensile strength.

Tri-xylyl phosphate has been shown to be identical in radiation stability to tri-tolyl phosphate.

Plasticizer content may be adjusted to suit the requirements of the formulation. For a given plasticizer, the decrease in elongation was independent of the plasticizer concentration. (Note that plasticizer ratios used were 35/65 and 45/55 parts by weight of plasticizer and polymer.)

(2) Filler type and content

No filler gave a better resistance to the degradative effect of radiation than was obtained in the absence of filler, but china clay and titanium dioxide (anatase) gave compounds that were no worse than those without filler, whether judged on the basis of actual elongation after exposure or on the basis of retention of initial elongation. Carbon black gave a very low initial elongation which was well retained. Whiting is very poor in retention of elongation and shared with carbon black the lowest actual elongation after exposure.

Addition of filler produced a small proportional diminution of the initial elongation, and the average effect of exposure to radiation was proportional to this initial elongation and independent of the filler content (zero to 20 per cent filler).

(3) Stabilizer

With Reoplex 100 plasticizer, stabilizer Mixture X is to be preferred; with tritolyl phosphate there was no difference between the two stabilizers.

(4) Color stability

With respect to color only, the best filler was anatase titanium dioxide, the best plasticizer was DOS, the best stabilizer was Mixture X. The best individual formulation was DOS with anatase titanium dioxide and stabilizer Mixture X.

Specimens containing precipitated whiting were almost as good as those with titanium dioxide. One effect observed was that the wire staples holding the specimens to the card were rusted and corroded in nearly all the specimens except those containing whiting. There was very little exudation.

Versluys, et al.,[55] found no weight loss in a 2-mil polyvinyl chloride film after exposure to a vacuum of 10^{-8} torr for 8 hours at ambient temperature. No weight loss was observed after exposure to ultraviolet for a total insolation of 120 hours in the 1300 to 1850 A band and 2140 hours in the 1100 to 1300 A band.

Blackmon, et al.,[5] exposed pigmented polyvinyl fluoride and polyvinyl chloride to ultraviolet for 96 hours in a vacuum of 3×10^{-7} torr at 80 F. The fluoride film darkened slightly, but no appreciable change in flexibility or tear strength was noted. The film retained an excellent appearance. The PVC film, however, turned brown, and voids and blisters from exuded plasticizer became evident. The film had a poor appearance.

Matacek[73] in his report on studies to determine the vacuum volatility of organic resins indicated that VMCH, a vinylchloride-acetate copolymer, lost 60 per cent of its weight when exposed to a temperature of 300 F for 24 hours. Polyvinyl butyral (Vinylite XYHL) lost 40 per cent of its weight. This temperature is, of course, high for these materials, but this would show their limitations for space applications.

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NJB/SP:all

APPENDIX A

COMPONENTS

TABLE A-1. TEST ENVIRONMENT AND RESULTS FOR HIGH-FORCE DYNAMIC-TEST MATERIALS: STRUCTURAL ADHESIVES(6)

Material and Type of Test	Radiation Exposure: Gamma [ergs/gm(C)]	Neutrons (n/cm²): Thermal	E>2.9 Mev	E>8.1 Mev	Ultimate Shear Strength, psi	Temperature: Avg. F	Fig. No.(e)	Pressure: Avg. (torr)	Fig No.(e)
FM-1000	0	0 (control specimens)	0	0	6302 6117 6004 5946 5955 6065/153[a]	77	-	760	-
High-Force Tester	1.1(10)	1.82(14) (vacuum irradiation)	1.83(15)	7.0(13)	6050 6096 6525 4830 4977 5696/729	157	D-16	$3x10^{-1}$	4.2
High-Force Tester	1.9(10)	5.1(14) (vacuum irradiation)	4.15(15)	1.7(14)	7016 6897 7689 7760 7340/419	-	-	5(-6)	4.3
Instron Tester	9..5(9)	1.34(14) (vacuum irradiation)	1.51(15)	5.95(13)	6082 6200 5900 6185 6442 6162/233	207	D-16	$3x10^{-1}$	4.2
Metlbond 302 (epoxy phenolic)	0	0 (control specimens)	0	0	2323 2510 2570 2526 2482/120[a]	77	-	760	-
High-Force Tester	1.6(10)	1.0(14) (vacuum irradiation)	2.33(15)	8.8(13)	2984 2938 2949 27[illegible]7 26[illegible]0 285[illegible] 2856/139	157[h]	D-16	$3x10^{-1}$	4.2
High-Force Tester	2.05(10)	4.57(14) (vacuum irradiation)	4.32(15)	1.98(14)	3613 3680 3310 3497 3455 3511/159	-	-	5(-6)	4.3

TABLE A-1. (Concluded)

Material and Type of Test	Radiation Exposure: Gamma [ergs/gm(C)]	Radiation Exposure: Neutrons (n/cm²) Thermal	Radiation Exposure: Neutrons (n/cm²) E>2.9 Mev	Radiation Exposure: Neutrons (n/cm²) E>0.1 Mev	Ultimate Shear Strength, psi	Temperature: Avg. F	Temperature: Fig. No.(c)	Pressure: Avg. (torr)	Pressure: Fig. No.(c)
Metlbond 302 (epoxy phenolic) Instron Tester	9.15(9)	1.34(14)	1.51(15)	5.95(13)	2586 2415 2355 2536 2643 2507/140	207[b]	D-16	3×10^{-1}	4.2

(a) Average value/standard deviation on an individual basis.

(b) Estimated value based on temperature of FM-1000.

(c) Figures given in reference 6.

TABLE A-2. SCREENING TESTS, PAINTS(18)

Test No.	Vehicle	Pigment	Manufacturer or Designation	Original Approximate a_s (a)	Change a_s: 11 Hours (b)	Change a_s: 22 - 25 Hours (b)	Change a_s: Extended
1	Acrylic	Rutile-Talc	Sherwin Williams Kemacryl M-49 MC-17	≈ 0.29	0.028	0.060 to 0.085	
2		Rutile	Fuller 8593 Insignia White 171-W-522	≈ 0.22	0.049	0.068 to 0.112	
3	Polyurethane	Rutile (?)	[illegible] Laminar X-500 White [illegible]-W-1	≈ 0.22	-	>0.20	
4	Silicone	Rutile	JPL Compounded JW 40	≈ 0.21	0.018	0.030 to 0.049	See Fig. 6 (c)
5		Zinc Sulfide	ZW 40	≈ 0.25	0.028	0.032 to 0.040	See Fig. 4 (c)
6		Zirconium Oxide	ZR 40	≈ 0.20	-	0.15	
			ZR 60	<0.20	-	0.12	
			ZROA 50	<0.20	-	0.19	
7	Acrylic		ZROA 75	<0.20	-	0.15	

(a) a_s Values listed only to indicate general range of value, no attempt was made to accurately measure a_s for those materials which degraded severely.
(b) Ultraviolet exposure at approximately 10 suns in vacuum.
(c) Figure given in Reference 18.

TABLE A-3. SCREENING TESTS, NONPAINT "WHITES"[19]

	System		Original Approximate α_s(a)	Change α_s: 22 - 24 Hours(b)	Change α_s: 48 Hours(c)	Remarks
(1)	Anodized high purity aluminum		≈ 0.25	0 to 0.021	0.045 to 0.072	
(2)	Al_2O_3 Tile (Gladding McBean and Company)		≈ 0.25	>0.15	-	
(3)	"Scotchcal" 3650 white ps (Minn. Mining and Mfg. Co. - white pigmented vinyl tape)		≈ 0.25	>0.10	-	
(4)	Tedlar 30 wh (Du Pont - white pigmented polyvinyl fluoride film)	Type A	≈ 0.25	>0.15	-	
		Type S	≈ 0.25	0.078(b)	-	
(5)	Tedlar - aluminized clear film (Du Pont - polyvinyl fluoride film)	Type 20A 200 ga.	≈ 0.25	0.088	-	
		Type 40S 200 ga.	≈ 0.25	0.047	-	
(6)	Teflon - TFE aluminized clear film (Du Pont - polyletrafluorethylene film)	10 mil	≈ 0.40	0.0352	-	"milky" film, high init. α_s
		5 mil	≈ 0.40	0.0160	-	
(7)	Teflon FEP - aluminized clear film (Du Pont - fluorinated ethylene-propylene)	Type "C" 1 mil	≈ 0.25	0.065	-	
		5 mil	≈ 0.25	0.117	-	
		Type "A" 1 mil	≈ 0.25	0	-	
		5 mil	≈ 0.25	0 to 0.013	0.015 to 0.019	

(a) Values listed to indicate general range of value.
(b) Ultraviolet exposure time of approximately 10 suns in vacuum.
(c) 20-hr exposure.

TABLE A-4. OPTICAL PROPERTIES OF BEST MATERIALS TESTED(18)

Material	Initial Properties α_s	Initial Properties $\epsilon_{300\ K}$	At Termination of 3 Months Venus Mission α_s (a)	At Termination of 3 Months Venus Mission $\epsilon_{300\ K}$
Zinc sulfide-silicona ZW 40	0.26	0.90	[illegible]	[illegible]
Zinc sulfide-silicona ZW 60	0.21	0.91	0.29	0.91
Aluminized FEP teflon (Type "A", 5 mil	0.26	0.84	0.31	0.84

(a) These values represent the maximum degradation that test data indicate may occur during a 3-month Venus mission.

(b) No significant change in ϵ_{300K} was found for any materials due to UV exposure.

TABLE A-5. REPRESENTATIVE MATERIAL RADIATIVE PROPERTIES[24]

Material	α	ϵ	α/ϵ Ratios
Metals			
Aluminum 6061 alloy			
As received	0.41	0.04	10.3
Machine polished and degreased	0.35	0.04	8.8
Sandblasted, 120 size grit	0.60	0.41	1.5
Aluminum 2024 alloy			
As received	0.27	0.02	13.5
Machine polished and degreased	0.31	0.06	5.2
QMU Beryllium alloy			
Rolled plate, chem. milled	0.48	0.11	4.4
Rolled plate, chem. milled, chem. polished	0.50	0.09	5.6
Gold			
Vacuum deposit gold on aluminum	0.24	0.04	6.0
Vacuum deposit gold on buffed titanium	0.33	0.05	6.6
Nickel			
Electroless nickel	0.45	0.17	2.6
Special surfaces on metals	0.63	0.66	0.95
Dow 17 on magnesium	0.53–0.72	0.50–0.82	0.95
Foils and adhesive-backed metals			
Fascal chrome aluminized mylar film	0.25	0.09	2.8
Bright gold foil	0.29	0.23	1.3

TABLE A-5. (Concluded)

Material	α	ϵ	α/ϵ Ratios
Paints (according to vehicle)			
Vinyl (phenolic)			
Dull black Micabond	0.93	0.84	1.1
Epoxy			
Skyspar (untinted white)	0.26	0.86	0.3
Silicone			
Fuller gloss white silicone	0.30	0.81	0.37
Fuller flat black silicone	0.89	0.81	1.1
Fuller aluminum silicone	0.23	0.20	1.2
Acrylic			
Kemacryl lacquer (white)	0.26	0.75	0.35
Kemacryl lacquer (black)	0.94	0.83	1.1
Miscellaneous			
Silica oxide			
5 mils of silica on magnesium	0.21	0.83	0.25
Adhesive-backed dielectrics			
Scotchcal (white) on aluminum	0.24	0.83	0.29
Ceramics			
Cermet (ceramic containing sintered metal)	0.65	0.58	1.1

ϵ = total hemispherical emissivity at 500° R
α = solar absorptivity, extraterrestrial

Values listed are averages of several determinations. Accuracy of the tabulated values is variable, but usually reliable to 10 per cent, except for very low emissivities.

TABLE A-6. RESULTS OF EXPOSURE OF COATING MATERIALS TO ULTRAVIOLET RADIATION AND VACUUM(24)

Test No.	Exposure Time (hr)	Material(1)	Substrate	Visible Changes	Measured Radiation Characteristics Before α	Before ϵ	After α	After ϵ
1	46	White Skyspar enamel, A	Dow 15 treated magnesium alloy	yellowed	0.25	0.85	0.37	0.87
		Gloss white silicone	Dow 15 treated magnesium alloy	slight yellowing	0.290	0.83	0.293	0.82
2	80	White Skyspar enamel, A (2 samples)	Dow 17 treated magnesium alloy	yellowish brown	0.22-0.23	0.82-0.85	0.39	0.82
		White Kemacryl lacquer	Dow 17 treated magnesium alloy	very slight yellowing	0.26	0.73	0.33	0.78
		Black Kemacryl lacquer	Dow 17 treated magnesium alloy	very slight change	0.94	0.81	0.92	0.79
		Aluminum silicone paint (2 samples)	Bare, untreated magnesium alloy	slight crackling	0.21-0.22	0.20-0.19	0.30-0.33	0.23-0.27
3	26	White Skyspar enamel, B	Dow 17 treated magnesium alloy	yellowish brown	0.24	0.83	0.37	0.85
		Gloss white silicone (2 samples)	Bare, untreated magnesium alloy	yellowish brown	0.27-0.33	0.83	0.30-0.35	-
		Gloss white silicone	Dow 15 treated magnesium alloy	yellowish brown	0.30	0.81	0.34	0.78
		White Kemacryl lacquer (2 samples)	Dow 17 treated magnesium alloy	very little change	0.27	0.73	0.32	0.76
		White Kemacryl lacquer (20 times intensity)	Dow 17 treated magnesium alloy	very little change	0.27	0.73	0.35	0.75
4	12	White Skyspar enamel, B (2 samples)	Dow 15 treated magnesium alloy	yellowish brown	0.26	0.86	0.31	0.84
		Gloss silicone white	Bare, untreated magnesium alloy	yellowish brown	0.30	0.81	0.29	0.83
		Sicon white, A	Dow 15 treated magnesium alloy	yellowish brown	0.25	0.83	0.33	0.83
		Dow 15 finish on magnesium (2 samples)	—	no change	0.23-0.17	0.06-0.07	0.28	0.07-0.08
		Dow 15 finish on magnesium (20 times intensity)	—	no change	0.18	0.09	0.30	0.14

TABLE A-6. (Concluded)

Test No.	Exposure Time	Material[1]	Substrate	Visible Changes	Measured Radiation Characteristics: Before		After	
					α	ϵ	α	ϵ
5	100	Gloss white silicone (2 samples)	Bare, untreated magnesium alloy	yellowish brown	0.30	0.81	0.33	0.84
		Sicon white, A	Dow 15 treated magnesium alloy	yellowish brown	0.26	0.84	0.37	0.83
		White Kemacryl lacquer (2 samples)	Dow 17 treated magnesium alloy	no change	0.26	0.74	0.35-0.32	0.76
		White Skyspar enamel, B	Bare, untreated magnesium alloy	yellowish brown	0.26	0.86	0.36	0.82
		Sicon white, (20 times intensity)	Dow 17 treated magnesium alloy	very dark brown	0.31	0.83	0.60	0.83
6	127	Unpigmented silicone resin	Dow 17 treated magnesium alloy	slight yellowing	—	—	—	—
		Barium titanate pigment, silicone resin	Dow 17 treated magnesium alloy	yellowed	—	—	0.34	0.84
		Strontium zirconate pigment, silicone resin	Dow 17 treated magnesium alloy	severe yellowing	—	—	0.47	0.85
		Zircon pigment, silicone resin	Dow 17 treated magnesium alloy	severe yellowing	—	—	0.45	0.85

Note: Intensity of ultraviolet radiation was six times solar ultraviolet intensity in space, except as noted.
Vacuum generally improved with time during each test, beginning at about 8×10^{-6} mm Hg and ending at about 1×10^{-6}.

(1) Tests No. 1 through 5 are commercial paints; No. 6 are laboratory-prepared paints.

TABLE A-7. COMMERCIAL MATERIALS EXPOSED TO ULTRAVIOLET RADIATION AND VACUUM(24)

Material	Manufacturer and Designation	Vehicle	Pigment
White Kemacryl laquer	Sherwin Williams, M49WC17	Acrylic resin	50 per cent TiO_2, 50 per cent talc
Black Kemacryl laquer	Sherwin Williams, M49BC12	Acrylic resin	Carbon black
White Skyspar enamel, A	Andrew Brown, SA-8818 A423-SA8818	Epoxy resin	TiO_2, tinted
White Skyspar enamel, B	Andrew Brown, A423-SA9185	Epoxy resin	TiO_2, untinted
Gloss white silicone	H. P. Fuller, 517-W-1	Silicone resin	TiO_2, untinted
Sicon white, A	Midland Industrial Finishes Co., 7X1153	Silicone	TiO_2, tinted
Sicon white, B	Midland Industrial Finishes Co., 7X1120	Silicone	TiO_2, tinted
Aluminum silicone paint	H. B. Fuller, 171-A-152	Silicone	Aluminum
Dow 15 bright metal finish	Dow Chemical Company	Chemical treatment; no vehicle or pigment	

TABLE A-8. LABORATORY-PREPARED PAINTS EXPOSED TO ULTRAVIOLET RADIATION AND VACUUM[2?]

Coating Composition (parts by weight)	Curing Cycle
146 parts sodium silicate K 356 parts zircon 890 parts water	0.5 hr 20° C, 1 hr 110° C, 2 hr 150° C, 1.5 hr 250° C, 1 hr 400° C
120 parts silicone resin 40 parts xylene	2 hr 20° C, 0.5 hr 85° C, 0.5 hr 120° C, 16 hr 155° C, 1 hr 210° C, 1 hr 265° C, 1 hr 325° C
120 parts silicone resin 70 parts barium titanate 40 parts xylene	2 hr 20° C, 0.5 hr 85° C, 0.5 hr 120° C, 16 hr 155° C, 1 hr 210° C, 1 hr 265° C, 1 hr 325° C
120 parts silicone resin 70 parts strontium zirconate 40 parts xylene	2 hr 20° C, 0.5 hr 85° C, 0.5 hr 120° C, 16 hr 155° C, 1 hr 210° C, 1 hr 265° C, 1 hr 325° C
120 parts silicone resin 70 parts zircon 40 parts xylene	2 hr 20° C, 0.5 hr 85° C, 0.5 hr 120° C, 16 hr 155° C, 1 hr 210° C, 1 hr 265° C, 1 hr 325° C
100 parts sodium silicate K 57 parts Aquablack B 50 parts water	88 hr 20° C, 1 hr 65° C, 1 hr 110° C, 2 hr 150° C
142 parts sodium silicate L 356 parts zircon 890 parts water	0.5 hr 20° C, 1 hr 110° C, 2 hr 150° C, 1.5 hr 250° C, 1 hr 400° C

Sodium silicate D has $Na_2O:SiO_2$ ratio of 1:2.00; sodium silicate K, 1:2.90

Silicone resin was Dow Corning No. 805

TABLE A-9. COLOR CHANGES OF ORGANIC COATINGS IN SIMULATED SOLAR RADIATION (23)

Vehicle	Pigment	Weight Ratio (solids) Vehicle/Pigment	Exposure, Sun-hours	Reflectivity[1], % at 380 mμ	440 mμ	600 mμ	700 mμ
Leonite 201-S	ZnO	1·08:4	0	33.0	93.8	96.5	95.6
			74	26.2	76.5	93.7	94.5
Leonite 201-S	ZnS	1·08:4	0	60.5	86.4	89.6	64.5
			74	52.5	78.5	88.3	64.0
Kel-F 800	ZnO	1:5	0	65.0	87.5	90.5	71.5
			108	38.0	47.0	57.5	64.5
Kynar	ZnO	1:5	0	36.0	84.0	90.0	93.5
			108	30.0	64.0	81.0	87.5
Exon 461	ZnS	1:4	0	63.0	86.0	89.0	68.0
			108	25.5	38.0	64.5	60.0
Viton A	ZnO	1:4	0	31.0	88.0	94.0	93.0
			108	26.0	68.0	87.5	90.0
RTV-11 Silicone	ZnO	1:1	0	26.0	91.0	92.0	90.5
			108	26.0	86.0	91.5	90.0
LTV-602 Silicone	ZnO	1:5	0	31.5	94.0	95.5	94.5
			108	31.0	93.0	94.5	93.0
Silicone 806 A	ZnO	1·5:1	0	24.0	86.5	84.0	81.5
			108	12.5	46.0	79.0	80.5
Silicone 806 A	ZnO	1·4:1	0	26.0	89.0	87.5	85.5
			108	17.0	56.0	83.5	83.5

[1] Relative to MgO

Leonite 201-S: A silicone-epoxy-acrylic resin supplied by Leon Chemical Industries. It was cured for 1/2 hour at 125° C.
Kel-F 800: Copolymer of Kel-F and vinylidene fluoride.
Exon 461: Copolymer of vinyl chloride and trifluorochloroethylene (Firestone Plastics Co.)
Kynar: Vinylidene fluoride homopolymer (Pennsalt Chemicals Corp.)
Viton A: Linear copolymer of vinylidene fluoride and hexafluoropropylene (Du Pont)
LTV-602 Silicone: Liquid dimethylpolysiloxane supplied by G.E.
RTV-11 Silicone: A silica-reinforced dimethylpolysiloxane liquid supplied with CaO and $CaCO_3$ fillers by G.E. a catalyst (Thermolite-12) is required for a cure at room temperature.

TABLE A-10. PHYSICAL EVALUATION OF COATINGS BEFORE AND AFTER ULTRAVIOLET IRRADIATION IN A VACUUM OF 1×10^{-5} mm Hg[24]

Coating Formulation	Test Period, (hr)	Flexibility – Mandrel Bend Test: 1/4 inch	Flexibility – Mandrel Bend Test: [illegible] inch	Flexibility – Mandrel Bend Test: 1/8 inch	Adhesion (a)	Color	Weight Loss, (%)	Quality – Remarks
Phenylmethyl silicone	0	S	S	S	E	Colorless	-	Tough and flexible
(unpigmented)	100	U	U	U	G	Amber	0.63	Hard - brittle
Leafing aluminum	0	S	S	S	G	Metallic	-	Tough and flexible
in silicone	100	S	S	S	G	Metallic	0.08	Tough and flexible
Zinc sulfide	0	U	U	U	E	White	-	[illegible]cks on bending
(30% PV in silicone) (b)	100	S	S	U	E	Slight yellow	0.05	[illegible]
Antimony oxide	0	S	U(c)	U(c)	E	White	-	Hard and slightly brittle
(30% PV in silicone)	100	S	U(c)	U(c)	E	Slight yellow	1.27	Hard and brittle
Calcium carbonate	0	S	S	S	E	Grayish	-	Tough and flexible
(30% PV in silicone)	100	S	S	U	E	Dark amber	0.34	Hard and slightly brittle
China clay	0	S	S	S	G	Dark gray	-	Tough and flexible
(30% PV in silicone)	100	S	S	S	G	Dark amber	0.80	Tough and flexible
Basic white lead carbonate	0	S	S	U	E	White	-	Hard and slightly brittle
(30% PV in silicone)	100	S	S	U	G	Slight yellow	2.92	Hard and slightly brittle
Basic white lead carbonate	0	U	U	U	G	White	-	Hard and brittle
(40% PV in silicone)	105	U	U	U	G	White	0.89	Hard and brittle
Butyl methacrylate	0	S	S	S	G	Colorless	-	Soft
(unpigmented)	105	S	U	U	G	Amber	62%	Brittle
Basic white lead carbonate	0	S	S	U	G	White	-	Slightly brittle
(40% PV in butyl methacrylate)	105	S	S	S	G	White	4.26	Slightly brittle
Butylated urea formaldehyde	0	S	S	S	G	Colorless	-	Hard and flexible
(unpigmented)	105	U	U	U	G	Amber	14.8	Hard and brittle
Basic white lead carbonate	0	U	U	[illegible]	[illegible]	White	-	Brittle
(40% PV in urea formaldehyde)	105	U	U	U		White	5.8[illegible]	Brittle

(a) E: excellent, G: good, S: satisfactory, U: unsatisfactory.
(b) PV: pigment-volume ratio.
(c) Slight surface cracks not extending through the coating.

TABLE A-11. TEST ENVIRONMENT AND RESULTS OF STATIC TEST: ELECTRICAL INSULATION(6,7)

Material Trade Name	Radiation Exposure: Gamma ergs/gm(C)	Neutron (n/cm²): Thermal	Neutron (n/cm²): E>2.9 Mev	Neutron (n/cm²): E>8.1 Mev	Time Until Test, days	Sample Weight: Original, gm	Sample Weight: Change, gm	Tensile Strength* (psi): at 25% Elongation	Tensile Strength* (psi): at 50% Elongation	Tensile Strength* (psi): at 100% Elongation	Tensile Strength* (psi): Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press. Avg., torr
Mylar C (1 mil) (polyester)	0	0 (control specimens) for vacuum test	0	0		—	—	17500 —	20300 —	Broken in jaws	24500 20700 22600/3369	70 55 63/22.2	77	760
Batch 1	1.3(9)	6.4(12) (vacuum irradiation)	1.5(13)	5.8(11)		0.1218 0.1201 0.1194 0.0012	+0.0009 0.0000 +0.0003 +0.0017	—	—	—	22800 16400 15000 21300 18875/[illegible]	85 — 15 75 —	80	5(-6)
	5.4(9)	9.2(13) (vacuum irradiation)	9.8(13)	3.7(12)		0.1191 0.1189 0.1125 0.1191	+0.0001 0.0000 +0.0001 +0.0001	—	—	—	17300 13800 12500 20300 17225/3768	40 50 — 80 57/23.6	80	5(-6)
Mylar C (1 mil) (polyester)	0	0 (control specimens) for air test	0	0		—	—	—	—	—	17400 17700 17600	47.2 52.5 49.7	77	760
Batch 2	4.9(9)	— (air irradiation)	1.3(15)	—		—	—	—	—	—	38000 38000 38000 38000	64 64 64 64	—	760
	8.9(9)	— (air irradiation)	2.2(15)	—		—	—	—	—	—	16500 15500 18500 16800	38.6 22.4 68.5 42	—	760
DC 7-170 (silicone)	0	0 (control specimens)	0	0		—	—	240 214 212 201 176 244 215/26.8	548 488 481 446 385 396 457/64.3	—	788 703 642 748 743 716 723/57.6	70 71 62 97 95 — 79/15.0	77	760
	9.03(9)	2.9(14) (vacuum irradiation)	1.4(15)	5.1(13)		3.8692 3.6586 3.7556	-0.0099 -0.0068 -0.0040	—	—	—	1690 1890 1715 1765/118	10 16 13 13/3.5	112**	2(-6)
	0	0 (control specimens)	0	0		—	—	[illegible] [illegible] [illegible] 247 327 200 264 254/50	488 420 355 414 584 386 — [illegible]41/90	— 833 818 — — — — 7[illegible]2/x	847 833 678 661 726 707 762 745/66	80 100 100 — 60 90 90 87/16	—	—

TABLE A-11. (Continued)

Material Trade Name	Radiation Exposure: Gamma [ergs/gm(C)]	Neutron (n/cm²): Thermal	Neutron (n/cm²): E>2.9 Mev	Neutron (n/cm²): E>8.1 Mev	Time Until Test, days	Sample Weight: Original, gm	Sample Weight: Change, gm	Tensile Strength* (psi): at % Elongation	Tensile Strength* (psi): at 50% Elongation	Tensile Strength* (psi): at 100% Elongation	Tensile Strength* (psi): Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press. Avg., torr
Kel-F-81 (fluorocarbon)	0	0 (control specimens)	0	0		—	—	3890	3670	4260	5240	15	77	760
	1.47(10)	3.4(14) (vacuum irradiation)	2.1(15)	7.8(13)		20.9974 21.2226 20.9352	-0.0415 -0.0806 Broken	— —	— —	— —	40 —	<1	115**	2(-6)
	5.5(9)	— (air irradiation)	1.08(15)	—		—	—	—	—	—	1568/3	0.58		
	8(9)	— (air irradiation)	2.2(15)	—		—	—	—	—	—	Specimen crumbled	—		
Mylar (10 mil) (polyester)	0	0 (control specimens)	0	0		—	—	13000 13500 13400 13300/264	13300 13500 13600 13467/224	15500 15100 15500 15367/290	16000 16000 17000 18300 16825/1090	103 120 130 140 123/15.7***	77	760
	2.42(10)	3.7(14) (vacuum irradiation)	2.2(15)	8.4(13)		1.2589 1.2578 1.2690	-0.0002 0.0000 -0.0009	—	—	—	17700 14000 — 15850/3280	<2 <2 — —	118**	2(-6)
Mylar A (3 mil) (polyester)	0	0 (control specimens)	0	0		—	—	18330 18180 17300 17800 17902/500	20650 20850 19833 20267 20400/424	Broke in jaws	23650 24350 22167 22133 23076/107	— 85 70 75 7/8.9	77	760
	1.3(9)	5.8(12) (vacuum irradiation)	1.5(13)	6.1(11)		1.2455 1.2643 1.2533 1.2477	+0.0003 +0.0007 0.0000 +0.0004	—	—	—	51600 56700 66000 64400 59675/6994	80 105 135 135 114/26.7	82	5(-6)
	7.0(9)	8.1(12) (vacuum irradiation)	6.1(13)	3.1(12)		1.2389 1.2632 1.2308 1.2668	+0.0007 +0.0005 +0.0003 +0.0002	—	—	—	60000 62667 56300 52600 57892/4889	130 145 110 85 118/29.1	82	5(-6)

TABLE A-11. (Continued)

Material Trade Name	Radiation Exposure: Gamma [ergs/gm(C)]	Neutron (n/cm²): Thermal	Neutron (n/cm²): E>2.9 Mev	Neutron (n/cm²): E>8.1 Mev	Time Until Test, days	Sample W[illegible]: Origi[illegible], gm	Sample W[illegible]: [illegible]ange, gm	Tensile Strength* (psi): at 25% Elongation	Tensile Strength* (psi): at 50% Elongation	Tensile Strength* (psi): at 100% Elongation	Tensile Strength* (psi): Ultimate	Ultimate Elongation, percent	Temperature Avg, °F	Press. Avg, torr
	1.5(8)	3.3(12) (air irradiation)	3.0(13)	1.1(12)	13	—	—	305 266 — 284 358 308/42	595 — — 498 684 592/110	—	837 757 649 591 684 704/106	75 125 30 65 50 69/41	80	—
	1.36(9)	1.8(13) (air irradiation)	2.5(14)	9.5(12)	13	—	—	426 395 460 390 471 428/35	— 659 — 732 722 704/43	—	584 [illegible] [illegible] 732 803 661/117	45 65 25 50 60 49/17	82	—
	9.1(7)	7.2(12) (vacuum irradiation)	1.7(13)	7.0(11)	8	3.5327 3.4987 3.7714 3.7630 3.7063	+0.0035 +0.0063 +0.0064 +0.0072 +0.0102	365 284 336 266 334 317/43	—	—	988 797 546 630 904 761/164	70 85 45 70 65 67/17	80	1.7(-7)
	3.9(8)	2.0(13) (vacuum irradiation)	5.8(13)	2.4(12)	7	3.7896 3.3989 3.9351 3.9861 3.6277	+0.0062 +0.0050 +0.0061 +0.0040 +0.0076	404 317 360 275 508 373/100	732 523 633 492 855 647/143	—	934 888 773 492 1010 819/223	60 75 55 62 57 62/9	9[illegible]	[illegible](-7)
	8.8(8)	2.8(13) (vacuum irradiation)	1.7(14)	6.4(12)	7	3.7915 3.4506 3.8441 3.6816 3.8052	+0.0049 +0.0001 +0.0044 +0.0046 +0.0089	476 511 461 463 — 477/24	886 821 — 886 — 824/3	—	956 1023 644 898 1068 918/178	55 55 45 52 60 53/6	90	4(-[illegible])
Kel-F-81	0	0 (control specimen)	0	0		—	—	4622 4495 — 4221 4171 4377/219	4622 4561 4286 4221 4234 4385/26	4558 4462 4242 4347 4265 4375/136	5897 5619 5081 5513 6070 5636/425	176 180 200 180 185 184/10	—	—
	6.5(7)	3.5(12) (air irradiation)	1.4(13)	6.0(11)	14	—	—	— 4178 [illegible] [illegible] 413[illegible]	— 4211 4106 4016 4111/115	— 4275 4149 4141 4188/79	5377 5409 5080 5238 5276/160	15**** 205 150 205 187/32	80	—
	1.5(8)	3.3(12) (air irradiation)	3.0(13)	1.1(12)	14	—	—	4166 4275 4137 4[illegible]43 4[illegible]04 4219/76	4099 4312 4269 4357 4204 4240/111	4166 4344 4225 4313 4141 4238/87	5477 5431 5325 5237 5334 5361/103	180 200 185 190 180 187/9	80	—
								4219/76	4240/111	4238/87	5361/103	187/9		

TABLE A-11. (Continued)

Material Trade Name	Radiation Exposure: Gamma ergs/gm(C)	Neutron (n/cm²): Thermal	Neutron: E>2 Mev	Neutron: E>8 Mev	Time Until Test, days	Sample Weights: Original, gm	Sample Weights: Change, gm	Tensile Strength (psi): at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Ultimate Elongation, percent	Temperature Avg, °F	Pressure Avg, torr
	6.8(8)	2.4(13) (air irradiation)	1.2(14)	4.9(12)	14	—	—	376 388 4116 3941 [illegible] 3913/214	— 3920 3984 4027 3984 3979/52	— 3964 4016 4071 3953 4005/57	5276 5227 5173 5110 5249 5207/71	400**** 190 210 215 200 204/12	82	—
	7.5(7)	4.6(12) (vacuum irradiation)	5.2(12)	2.35(11)	8	22.2416 22.5782 22.1467 16.6356 23.5746	−0.0037 −0.0034 +0.0002 −0.0019 −0.0015	4458 4590 4376 4434 4514 4474/92	4458 4526 4408 4304 4358 4411/95	4392 4717 4637 4521 4483 4550/140	5605 5610 4474 5521 5821 5406/579	104 150 170 145 [illegible] 1[illegible]0/34	80	1.7(-7)
	9.1(7)	7.8(12) (vacuum irradiation)	1.7(13)	7.0(11)	8	22.2692 22.4512 21.9510 16.6468 23.5801	−0.0006 −0.0007 −0.0040 −0.0010 +0.0002	4405 3841 4487 4539 4328 4320/300	4340 3777 4520 4628 4268 4307/300	4405 3809 — 445[illegible] 4328 4259/333	5636 5633 5626 5384 5440 55[illegible]/108	202 166 55**** 157 172 170/22	80	1.7(-7)
	4.45(8)	7.95(13) (vacuum irradiation)	5.45(13)	2.1(12)	10	22.6049 22.0014 16.7015 16.7025 23.1123	−0.0009 −0.0068 +0.0007 −0.0007 −0.0001	4437 4599 4379 4296 4484 4439/130	4405 4632 4207 4252 4330 4365/163	4373 4567 4379 4296 4467 4376/129	5733 5798 5367 5436 5616 5590/185	165 185 175 180 200 161/15	90	4(-7)
Mylar A	0	0 (control specimens)	0	0	—	—	—	16300 16600 16900 16600 17000 16680/301	17000 17600 17800 17500 17500 17480/344	19000 19700 19800 19500 19400 19480/344	20500 22000 19800 — 20800 20825/946	119 132 100 — 110 115/14	—	—
	6.8(8)	2.4(13) (air irradiation)	1.2(14)	4.9(12)	16	—	—	16500 16500 16800 16600 16350/389	17200 17200 17500 17500 17350/146	18600 18800 19200 18800 18850/291	21800 22000 21300 21400 21625/340	140 130 125 150 136/12	82	--
	1.07(10)	1.9(14) (air irradiation)	2.[illegible](15)	8.2(13)	16	—	—	15400 15600 15500 15500 15500 15500/86	15700 15800 15900 15900 16800 16020/473	— — — 16200 — —	16000 16300 16500 16200 16800 16360/344	80 — 75 100 60 79/19	100	—
	4.45(8)	1.95(13) (vacuum irradiation)	5.45(13)	2.1(12)	9	1.4195 1.4059 1.4067 1.4190 1.4184	+0.0003 +0.0001 +0.0005 0.0000 +0.0019	16500 16500 16500 16500 16600 [illegible]	17500 17300 17200 17300 17300 17320/125	19200 19000 19200 19500 19300 19240/215	21500 19500 21500 22000 19700 20840/1075	131 105 132 135 110 123/13	90	4(-7)

TABLE A-11. (Continued)

Material Trade Name	Radiation Exposure: Gamma [ergs/gm(C)]	Neutron (n/cm²): Thermal	Neutron (n/cm²): E>2.9 Mev	Neutron (n/cm²): E>8.1 Mev	Time Until Test, days	Sample Weights: Original, gm	Sample Weights: Change, gm	Tensile Strength* (psi): at 25% Elongation	Tensile Strength* (psi): at 50% Elongation	Tensile Strength* (psi): at 100% Elongation	Tensile Strength* (psi): Ultimate	Ultimate Elongation, percent	Temperature Avg, °F	Press. Avg, torr
	5.9(9)	1.18(14)	6.58(14)	—	7	1.4112	-0.0016	15300	16700	—	17800	110	160	8(-7)
		(vacuum irradiation)				1.3924	0.0000	16300	16800	—	17500	95		
						1.3972	-0.0002	16500	16800	—	18500	105		
						1.3993	-0.0005	16200	16700	—	17300	75		
						1.4003	+0.0001	16000	16500	17300	17300	100		
								16060/516	16700/129	—	17640/430	97/15		
	1.05(10)	1.32(14)	1.65(15)	5.9(13)	7	1.4154	-0.0010	—	—	—	19200	—	160	8(-7)
		(vacuum irradiation)				1.4196	-0.0011	—	—		16700	80		
						1.4013	-0.0014	—	—		175[illegible]	20		
						1.3976	+0.0001	15800	15800		158[illegible]	50		
						1.3982	-0.0021	—	—		16000	15		
								—	—		17056/1462	41/32		
Mylar C	0	0	0	0	—	—	—	16300	19200	—	21300	60	—	—
		(control specimens)						16000	18700	—	—	—		
								16200	18700	24500	24500	100		
								16200	17500	24000	18500	121		
								16300	18500	24500	28500	130		
								16200/129	18520/731	24333/295	25700/3497	103/34		
	6.8(8)	2.4(13)	1.2(14)	4.9(12)	13	—	—	15500	17500	21000	23700	110	92	—
		(air irradiation)						15200	17500	19300	24000	110		
								14800	16500	—	16500	50		
								15500	17500	22500	26300	110		
								15000	17000	20500	22500	105		
								15200/301	17200/430	20825/1554	22600/4213	97/26		
	1.36(9)	1.8(13)	2.5(14)	9.5(12)	13	—	—	15500	18300	21500	23700	105	32	—
		(air irradiation)						15200	17500	21500	24300	125		
								15700	18000	22500	24400	105		
								15000	17000	—	19300	70		
								15200	17200	21000	22500	105		
								15320/301	17500/559	21625/729	22840/2193	102/24		
	6.0(9)		26(15)		16	—	—	16000	—	—	16700	35	100	—
		(air irradiation)						—			18800	60		
								—			20000	70		
								—			—	—		
								—			18500/1949	55/21		
	4.45(8)	1.95(13)	5.45(13)	2.1(12)	9	0.1470	-0.0014	16300	18600	—	24000	90	90	4(-7)
		(vacuum irradiation)				0.1498	-0.0027	—	—	—	—	110		
						0.1503	-0.0007	16500	19000	—	21300	70		
						0.1462	-0.0012	16500	18500	22000	27300	120		
						0.1494	-0.0002	[illegible]	20000	26000	28700	106		
								[illegible]	19250/729	24000/x	25325/2283	100/21		
	9.1(8)	2.8(13)	1.6(14)	6.0(13)	9	0.1475	-0.0016	16300	18500	24500	24500	100	90	4(-7)
		(vacuum irradiation)				0.1485	+0.0011	16800	19000	—	23700	90		
						—	—	—	—	—	—	—		
						0.1422	0.0000	16700	19000	—	20700	96		
						0.1433	-0.0003	16200	19000	—	26000	98		
								16500/291	18875/243	—	23725/2574	96/5		

16500/291 18875/243 — 23725/2574 96/5

TABLE A-11. (Continued)

Material Trade Name	Radiation Exposure: Gamma ergs/gm(C)	Neutron (n/cm²): Thermal	Neutron (n/cm²): E>2.9 Mev	Neutron (n/cm²): E>8.1 Mev	Time Until Test, days	Sample Weight: Original, gm	Sample Weight: Change, gm	Tensile Strength* (psi): at 2[illegible] Elongation	Tensile Strength* (psi): at 50% Elongation	Tensile Strength* (psi): at 100% Elongation	Tensile Strength* (psi): Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press. Avg., torr
Geon 2046 Elastomer Die C Specimen	0	0 (control specimens)	0	0		—	—	. 898 349 644 1080 647 766/238	1171 1498 1255 1146 1451 1171 1282/139	1865 1948 1771 1508 -- 1515 172[illegible]/186	2934 3123 2951 2580 2722 2617 2[illegible]21/214	295 190 240 360 265 350 300/67	—	—
	6.8(8)	2.4(13) (air irradiation)	1.2(14)	4.9(12)	16	—	—	665 575 516 669 600 605/66	1138 1165 1158 1138 1117 1143/21	1541 1475 1535 1539 1493 1517/28	2539 2593 2554 2570 2540 2559/23	— 330 330 320 300 320/15	82	--
	6.0(9)	(air irradiation)	1.26(15)		16	—	—	855 864 824 714 736 730 787/59	1244 1254 1286 1178 919 1192 1179/145	1904 2028 1812 1810 1815 1745 1852/112	2561 2556 2405 2394 2375 2445 2456/71	170 172 175 182 170 185 176/16	100	—
	1.07(10)	1.9(14) (air irradiation)	2.3(15)	8.2(13)	1[illegible]	—	—	875 870 744 692 872 712 794/72	1483 1425 1281 1175 1345 1222 1323/124	2082 2041 2110 2078 2075 1960 2058/59	2695 2690 2621 2579 2659 2709 2659/51	130 135 135 130 135 139 134/4	100	--
	3.9(8)	2.0(13) (vacuum irradiation)	5.8(13)	2.4(12)	13	2.9826 3.3903 3.0741 3.6627 3.5968	-0.0076 -0.0065 -0.0120 -0.0069 -0.0079	1008 800 890 860 767 865/104	1411 1192 1295 1273 1220 1258/94	1875 1685 1771 1872 1815 1804/82	2941 2900 2860 2922 2870 2899/35	315 346 345 300 325 325/20	90	4(-7)
	1.3(10)	1.2(15) (vacuum irradiation)	2.0([illegible])	9.8(13)	6	3.1583 3.2555 3.2338 3.1203 3.0895	-0.1556 -0.2141 -0.2116 -0.1557 -0.1984	1174 1334 1539 1117 1288 1290/181	— — 2078 — 1989 2034/x	—	2126 2230 — 2422 2260 2260/144	80 60 — 70 55 66/12	160	8(-7)
Geon 8800 Elastomer Die C Specimen	0	0 (control specimens)	0	0		—	—	1071 1746 1641 15[illegible] [illegible] [illegible] 1581/307	1714 2077 2089 1985 2169 2018 [illegible]09/180	2[illegible]1 2536 2[illegible]92 2346 -- 2425 2392/153.3	3289 2830 2966 2651 2924 2874 2956/173.0	270 — 315 300 300 300 297/15.7	—	—

TABLE A-11. (Continued)

Material Trade Name	Radiation Exposure: Gamma (ergs/gm(C))	Neutron (n/cm²) Thermal	Neutron E>2.9 Mev	Neutron E>8.1 Mev	Time Until Test, days	Sample Weights: Original, gm	Sample Weights: Change, gm	Tensile Strength* (psi) at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press. Avg., torr
	6.8(8)	2.40(13) (air irradiation)	1.2(14)	4.9(12)	15	—	—	1541 1611 1599 1481 1723 1643/163	1927 2024 2166 1851 2007 1994/135	2199 2307 2400 2185 [illegible] 2276/98	2650 2637 2699 2555 2613 [illegible]/58	350 300 260 390 280 316/56	82	--
	6.0(9)		1.26(14) (air irradiation)		16	—	—	— 1908 1773 1852 1845/69	— 2402 2204 2306 2311/105	— 2930 2795 3005 2910/124	— [illegible] 3164 3219 3185/76	110 130 128 125 123/10	100	--
	1.07(10)	1.9(14) (air irradiation)	2.3(15)	8.2(13)	16	—	—	2230 — — 2142 2055 [illegible]/67	— — — 2988 3062 2975/x	—	2602 3395 3692 3676 3465 3372/469	45 70 82 75 65 67/16	100	—
	3.9(8)	2.0(13) (vacuum irradiation)	5.8(13)	2.4(12)	7	7.3583 7.2144 7.3687 7.2065 7.1097	+0.0043 +0.0057 +0.0058 +0.0055 +0.0067	— 1641 1782 1591 1148 1586/[illegible]	2051 2089 2093 1895 1611 1948/207	— 2492 2407 2383 2162 2347/150	2835 2966 2833 2743 3177 2911/187	290 315 290 260 265 284/24	[illegible]	[illegible](-7)
	1.3(10)	1.2(15) (vacuum irradiation)	2.0(15)	9.8(13)	6	7.1683 7.4593 7.4964 7.1806 7.1872	-0.3404 -0.3181 -0.3163 -0.3518 -0.3094	— 3259 — — — —	— — — 4417 4138 4283/x	—	— 3859 4178 4417 4132 3996.3/507.0	— 25 45 60 50 45/14.7	160	6(-7)
Betane 5740K1 Elastomer Die C Specimen	0	0 (control specimens)	0	0		—	—	748 657 741 748 783 783 842 790 743/72	884 898 865 884 855 907 956 900 893/35	1283 1084 988 978 960 1092 1084 1080 1082/46	5346 — — 4800 2855 6012 9745 5048 4573/1846	535 — — 660 615 540 — 585 587/34	—	—
	1.36(9)	1.8(13) (air irradiation)	2.5(14)	[illegible](12)	13	—	—	[illegible] [illegible] [illegible] 636 708 672/28	884 881 855 889 889 856/24	952 966 920 956 958 954/[illegible]	4149 3350 3815 4080 3765 3832/344	390 510 630 650 550 588/60	82	—

TABLE A-11. (Continued)

Material Trade Name	Radiation Exposure: Gamma ergs/gm(C)	Neutron (n/cm²): Thermal	Neutron: >2.9 Mev	Neutron: >8.1 Mev	Time Until Test, days	Sample Weight: Original, gm	Sample Weight: Change, gm	Tensile Strength* (psi): at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press. Avg., torr
	6.8(8)	2.4(13) (air irradiation)	1.2(14)	4.9(12)	10	—	—	—	—	—	1609 1666 1542 1359 1818 1599/197	0.42 0.38 0.34 0.27 0.47 0.38/.09	82	—
	1.36(9)	1.8(13) (air irradiation)	2.5(14)	9.5(12)	10	—	—	—	—	—	1542 1646 1492 1560/91	0.34 0.37 0.45 0.39/.06	82	—
	1.8(8)	8.4(12) (vacuum irradiation)	1.85(13)	7.6(11)	8	23.3102 23.8341 23.0900 23.8446 23.8812	+0.0153 +0.0157 +0.0137 +0.0105 +0.0090	—	—	—	2001 2201 1977 2066 2115 2073/100	0.58 0.74 0.57 0.63 0.60 0.62/.07	80	1.7(-7)
	4.2(8)	1.9(13) (vacuum irradiation)	4.5(13)	1.8(12)	8	22.9615 22.8704 23.8973 22.9133 23.7812	-0.0033 -0.0036 -0.0088 -0.0058 -0.0053	—	—	—	2243 2220 1930 2383 2375 2210/191	0.65 0.75 0.86 0.77 0.74 0.75/.09	90	4(-7)
	8.8(8)	2.8(13) (vacuum irradiation)	1.7(14)	6.4(12)	8	23.0949 22.9674 23.5830 23.7765 22.8814	-0.0060 -0.0048 -0.0077 -0.0056 -0.0043	—	—	—	2148 2368 2151 2351 2234 2250/95	0.66 0.50 0.72 0.73 0.91 0.70/.18	90	4(-7)
Kynar	0	0 (control specimens)	0	0		—	—	—	—	—	4000 5133 4883 6167 5500 7000 6900 5598/1169	— — — 10 5 10 10 8.75/2.42	—	—
	0	0 (vendor data)	0	0		—	—	—	—	—	7000	300	—	-
	6.5(7)	3.5(12) (air irradiation)	1.4(13)	6.0(11)	13	—	—	—	—	—	5167 6000 6167 7467 9033 5967/575	10 10 5 10 25 12/7.6	80	—

TABLE A-11. (Continued)

Material Trade Name	Gamma ergs/gm(C)	Neutron (n/cm²) Thermal	Neutron E>2.9 Mev	Neutron E>8.1 Mev	Time Until Test, days	Sample Weight Original, gm	Sample Weight Change gm	Tensile Strength* (psi) at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press. Avg., torr
	1.07(10)	1.9(14) (air irradiation)	2.3(15)	8.2(14)	16	—	—	844 789 753 735 765 777/47	993 1020 982 944 982 984/33	1183 1291 1166 1168 1225 1215/46	2625 2720 2540 2621 2835 2668/127	300 292 292 298 310 298/8	100	—
	3.9(10)	2.8(14) (air irradiation)	6.1(15)	2.6(14)	16	—	—	868 1027 829 885 855 893/85	1237 1449 1164 1170 1185 1245/120	1907 — 1842 1770 1709 1807/96	24[illegible] 24[illegible] 2565 2380 2410 2453/80	120 115 135 128 130 126/9	100	—
	9.1(8)	2.8(13) (vacuum irradiation)	1 (14)	6.0(12)	[illegible]	1.6393 1.6330 1.7473 1.8386 1.7363	+0.0024 +0.0006 +0.0020 +0.0020 +0.0016	731 815 789 780 749 773/30	914 976 894 900 920 921/35	1111 1161 1092 1080 1105 1110/35	5499 4796 5591 5258 5460 5321/342	552 555 520 550 572 550/22	90	4(-7)
	1.3(10)	1.2(15) (vacuum irradiation)	2.0(15)	9.8(13)	6	1.7567 1.8095 1.7596 1.7231 1.7884	-0.0112 -0.0166 -0.0133 -0.0130 -0.0103	657 556 723 572 701 642/72	960 927 1110 956 1058 1004/82	1644 1483 1710 1594 1696 1625/98	3420 3770 4012 3571 3762 3707/255	205 245 250 230 225 231/19	160	6(-7)
	2.6(10)	4.88(14) (vacuum irradiation)	5.36(15)	2.09(14)	10	1.7709 1.8673 1.7740 1.7357 1.7511	-0.0509 -0.0512 -0.0472 -0.0421 -0.0515	565 667 855 1091 592 754/226	1418 1359 1841 2369 1500 1697/434	—	2525 2842 3025 3195 3319 2981/341	85 80 0 70 90 81/9	200	6( )
Duroid 5600	0	0 (control specimens)	0	0		—	—	—	—	—	2919 2492 2262 2167 2316 2291/140	0.82 0.91 0.79 0.69 0.94 0.83/.11	—	—
	1.5(8)	3.3(12) (air irradiation)	3.0(13)	[illegible](12)	10	—	—		—	—	2193 1596 1800 1972 1890 1890/257	0.48 0.47 0.41 0.64 0.53 0.51/.10	80	—

TABLE A-11. (Continued)

Material Trade Name	Radiation Exposure: Gamma (ergs/gm(C))	Neutron (n/cm²): Thermal	Neutron (n/cm²): E>2.9 Mev	Neutron (n/cm²): E>8.1 Mev	Time Until Test, days	Sample Weights: Original, gm	Sample Weights: Change, gm	Tensile Strength* (psi): at 25 Elongation	Tensile Strength* (psi): at 50% Elongation	Tensile Strength* (psi): at 100% Elongation	Tensile Strength* (psi): Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press. Avg., torr
	1.5(8)	3.3(12) (air irradiation)	3.0(13)	1.1(12)	13	—	—	—	—	—	5850 6117 5833 6367 5950 6023/226	10 10 10 5 10 9/2.24	80	—
	1.36(9)	1.8(12) (air irradiation)	2.5(14)	9.5(12)	13	—	—	—	—	—	6367 6200 8233 7333 5833 6793/982	10 10 5 5 10 8/2.74	82	—
	6.2(7)	4.5(12) (vacuum irradiation)	6.3(12)	2.8(12)	9	1.7303 1.5895 1.6308 1.4761 1.5520	0.0030 -0.0009 -0.0015 +0.0009 +0.0006	—	—	—	6550 5383 5417 5417 5167 5587/548	5 20 15 10 15 16.25/6.77	80	1.7(-7)
	1.8(8)	8.4(12) (vacuum irradiation)	1.85(13)	7.6(11)	8	1.5288 1.5462 1.5446 1.5016 1.5072	+0.0019 +0.0091 +0.0024 +0.0020 +0.0025	—	—	—	5283 4583 5667 6000 5283 5363/529	15 5 5 — 10 8.75/4.80	80	1.7(-7)
	9.4(8)	2.8(13) (vacuum irradiation)	1.5(14)	5.6(12)	10	—	—	—	—	—	5667 5333 5250 6117 5800 5633/359	10 — 10 10 — 10/0	90	4(-7)

* Values given as: average value/standard deviation on an individual basis.

** Estimated value based on temperature of natural rubber.

*** Average value/standard deviation on an individual basis.

Tested under atmospheric conditions.

**** Data point not used in average

TABLE A-12. TEST ENVIRONMENTS AND RESULTS OF STATIC TESTS: DIELECTRIC MATERIALS(6,7)

Material Trade Name	Radiation Exposure: Gamma [ergs/gm(C)]	Neutron (n/cm²): Thermal	Neutron (n/cm²): E>2.9 Mev	Neutron (n/cm²): E>8.1 Mev	Time Until Test, days	Sample Weight: Original, gm	Sample Weight: Change, gm	Tensile Strength* (psi): at 25% Elongation	Tensile Strength* (psi): at 50% Elongation	Tensile Strength* (psi): at 100% Elongation	Tensile Strength* (psi): Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press. Avg., torr
Marlex 6002 (14 mil)	0	0 (control specimens)	0	0		—	—	3000 3286 3643 3507 3700 3414 3714 3466/264	2714 2571 3014 2943 3107 2921 3014 2898/198	2714 2357 2561 2507 2643 2864 2943 2657/217	4071 2571 3343 3661 4086 3229 3521 3[illegible]7/560	785 1100 775 960 960 860 910 907/120	—	—
	1.5(8)	3.3(12) (air irradiation)	3.0(13)	1.1(14)	14	—	—	— — — 3571 3571	— — — 3071 3071	— — — 2571 2571	4286 4071 3893 3964 4054/191	— — — ~800 ~800	80	—
	1.36(9)	1.8(13) (air irradiation)	2.5(14)	9.5(12)	14	—	—	—	—	—	4307 4079 4057 3993 [illegible] 4087/135	20 15 20 5 10 14/6	82	—
	1.8(8)	8.4(12) (vacuum irradiation)	1.85(13)	7.6(11)	8	1.3796 1.3510 1.2338 1.2232 1.3605	+0.0002 +0.0007 +0.0001 +0.0004 −0.0002	4214 2929 3929 3857 4107 3807/552	3464 — — 2714 — 3098/—	—	4356 4286 4107 3964 4250 4193/169	720 975 1030 690 825 848/146	8[illegible]	1.7(−7)
	4.5(8)	1.95(1[illegible]) (vacuum irradiation)	5.45(13)	2.1(12)	10	1.3427 1.3553 1.3485 1.3441 1.3169	+0.0005 −0.0005 −0.0003 −0.0004 −0.0003	3571 4071 3786 4143 3786 3871/246	3000 — 3071 3286 2857 3054/184	—	4429 4500 4464 4393 [illegible] 4400/123	800 — 430 837 675 711/198	90	4(−7)
	9.4(8)	2.8(13) (vacuum irradiation)	1.6(14)	6.0(12)	10	1.2526 1.2871 1.2490 1.3067 1.3116	+0.0012 +0.0012 +0.0007 +0.0008 +0.0010	3714 — 4071 — 4214 4000/295	3071 — 3143 — 2857 3024/169	— — 2643 — — 2643	3679 — 4214 — 4429 4107/443	725 — 640 — 660 675/50	9[illegible]	4(−7)
Teflon TFE (10 mil)	0	0 (control specimens)	0	0		—	—	1863 [illegible] [illegible] 1800/111	2109 2318 2036 2136 2150/137	2209 2590 2263 — 2381/181.4	3572 3845 3418 5363 4049/894.0	255 260 240 330 271/42.5	—	—

TABLE A-12. (Continued)

Material Trade Name	Gamma [ergs/gm(C)]	Radiation Exposure: Neutron (n/cm²) Thermal	E>2.9 Mev	E>8.1 Mev	Time Until Test, days	Sample Weights: Original, gm	Change, gm	Tensile Strength* (psi): at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press. Avg., torr
	6.5(7)	3.5(12) (air irradiation)	1.4(13)	6.0(11)	11	—	—		—	—	1772 1663 1709 1700 1772 1723/51.1	30 70 65 70 65 60/17.0	80	—
	1.5(8)	3.3(12) (air irradiation)	3.0(13)	1.1(12)	11	—	—	—	—	—	1690 1645 1709 1700 1672 1683/27.0	40 35 45 30 30 36/6.5	80	—
	6.8(8)	2.4(13)	1.2(14)	4.9(12)	x			Too brittle to test						
	7.5(7)	4.6(12) (vacuum irradiation)	5.2(12)	2.35(11)	9	2.2295 2.2153 2.3813 2.2462 2.2907	-0.0012 -0.0005 -0.0003 -0.0009 -0.0003	1772 1590 1727 1727 1681 1699/70	1999 1863 1909 1954 1954 1936/58	2181 2136 2136 2181 2227 2172/34.0	3272 3362 3272 3227 2318 3090/440	235 260 260 230 210 239/21.4	80	1.7(-7)
	9.1(7)	7.8(12) (vacuum irradiation)	1.7(12)	7.0(11)	9	2.2188 2.1787 2.2885 2.1411 2.3858	+0.0003 +0.0003 -0.0001 +0.0008 0.0000	1636 1636 1545 1681 1545 1609/58	1909 1863 1772 1909 1818 1854/59	2030 2090 2045 2136 2090 2090/32.1	2862 2363 2818 2636 2727 2681/175	200 150 200 190 180 184/20.8	80	1.7(-7)
	1.68(8)	1.7(12) (vacuum irradiation)	1.9(13)		10	—	—	1590 1772 1545 1636/134	1890 2136 1881 1969/151	2136 2363 2118 2206/142	3863 2909 2227 3000/682	190 180 120 163/39.4	85	2.3(-7)
	4.45(8)	1.95(13) (vacuum irradiation)	5.45(13)	2.1(12)	10	2.2441 2.3956 2.2721 2.3678 2.3278	-0.0009 -0.0005 -0.0006 -0.0002 -0.0003	1590 1681 1727 1727 1681 1681/59	1654 1790 1818 1818 1745 1764/71	— — 2054 2027 1900 1997/77.2	1772 2136 2409 2209 2136 2132/228	60 125 140 134 143 120/34.5	90	4(-7)
	5.08(8)	8.31(12) (vacuum irradiation)	6.9(13)	2.77(12)	9	—	—	1264 1336 1345 1315/48	1291 1336 1364 1330/43	—	1409 1373 1418 1400/23.8	98 80 95 91/9.65	87	2.5(-7)
Teflon TFE (40 mil) Die A Specimen	0	0 (control specimens)	0	0		—	—	2014 1848 1985 1864 1929/81	2108 1972 2120 1978 2044/72	2209 2251 2106 2091 2177/120	2905 2786 2833 2796 2830/58	400 275 275 300 313/61	—	—

TABLE A-12 (Continued)

Material Trade Name	Radiation Exposure: Gamma [ergs/gm(C)]	Radiation Exposure: Neutron (n/cm²) Thermal	Radiation Exposure: Neutron (n/cm²) E>2.9 Mev	Radiation Exposure: Neutron (n/cm²) E>8.1 Mev	Time Until Test, days	Sample Orig.., gm	Sample Change, gm	Tensile Strength* (psi) at 25% Elongation	Tensile Strength* (psi) at 50% Elongation	Tensile Strength* (psi) at 100% Elongation	Tensile Strength* (psi) Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press. Avg torr
	1.5(8)	3.3(12) (air irradiation)	3.0(13)	1.1(12)	13	—	—	—	—	—	2000 1701 1847 1694 1770 1802/129	1 1 1 1 1 1/0	80	—
	6.8(8)	2.40(13) (air irradiation)	1.2(14)	4.9(12)	13	—	—	—	—	—	[illegible] [illegible] 402 742 704 519/163	1 1 1 1 1 1/0	82	—
	9.1(7)	7.8(12) (vacuum irradiation)	1.7(13)	7.0(11)	6	5.8602 5.8667 5.8600 5.8583	-0.0001 -0.0003 -0.0004 -0.0004	1762 1772 — 1607 1714/97	— — — 1539 —	—	1762 1778 1493 1536 1642/136	65 25 45 50 46/19	80	1.7(-7)
	3.9(8)	1.9(13) (vacuum irradiation)	4.4(13)	1.7(12)	10	5.8218 5.8271 5.7846 5.8157 5.7941	+0.0003 -0.0006 -0.0007 -0.0003 -0.0007	— — — — 1742 1742	—	—	1773 1772 1830 1816 1798 1798/25	15 22 45 20 25 25/13	90	4(-7)
Teflon FEP (10 mil)	0	0 (control specimens)	0	0		—	—	1970 2040 2000 2180 2000 1910 2000 1970 2010 2000 2000 2000 2020 2040 2010/79	2040 2120 2050 2280 2070 2050 2060 2060 2090 2050 2070 2070 2110 2100 2087/66	2080 2150 2140 2340 2120 2100 2120 2100 2140 2110 — 2120 2150 2150 2140/78	— — — 3480 — 3830 3580 3800 3700 4100 3620 3860 3760 3910 3770/201	— — — 310 — 367 325 363 323 381 350 369 360 372 352/23	—	—
	6.5(7)	3.5(12) (air irradiation)	1.4(13)	6.0(11)	16	—	—	2000 [illegible] [illegible] [illegible] 2013/[illegible]	2080 2100 2070 2100 2088/15	2130 2130 2130 2150 2135/10	2420 3550 2800 2300 2768/607	250 370 300 240 290/63	80	—

TABLE A-[illegible] (Continued)

Material Trade Name	Gamma [ergs/gm(C)]	Radiation Exposure: Neutron (n/cm²) Thermal	E>2.9 Mev	E>8.1 Mev	Time Until Test, days	Sample Weights: Original, gm	Change, gm	Tensile Strength* (psi): at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press. Avg., torr
	6.8(8)	2.4(13) (air irradiation)	1.2(14)	4.9(12)	16	—	—	2000 1950 1950 1900 1950/49	2040 2000 2000 1950 1998/44	2030 2000 1970 1940 1985/35.4	2300 2250 2250 2180 2245/49.4	140 220 140 210 177.5/43.5	82	—
	7.5(7)	4.6(12) (vacuum irradiation)	5.2(12)	2.35(11)	9	2.1568 2.1449 2.1317 2.1663 2.1632	0.0104 -0.0001 -0.0037 +0.0003 -0.0009	2050 2050 2030 2050 2070 2050/17	2100 2100 2100 2100 2150 2110/21	2160 2160 2150 2150 2200 2160/21.1	3800 4020 3780 3[illegible]30 3[illegible]70 3820/127.5	365 430 360 365 345 377/30.0	80	1.7(-7)
	1.8(8)	8.4(12) (vacuum irradiation)	1.85(13)	7.6(11)	9	2.1591 2.1834 2.1576 2.1908 2.1562	0.0000 -0.0083 -0.0032 -0.0017 -0.0081	2000 2000 2100 1800 1800 1940/129	2100 2070 2150 1870 1850 2008/129	— 2150 — 1950 1950 2017/117.0	3600 3050 3830 3300 — 3445/336.2	350 320 395 330 — 349.5/34.2	80	1.7(-7)
	4.45(8)	1.95(13) (vacuum irradiation)	5.45(13)	2.1(12)	10	2.1542 2.1530 2.1480 2.2139 2.1410	+0.0021 +0.0015 +0.0013 -0.0023 -0.0108	1960 1950 1960 2000 1940 1962/26	2010 1990 2030 2050 1970 2010/34	2070 2060 2060 2120 — 2077.5/59.0	2230 2400 3000 2320 2260 2442/322.0	270 280 — 275 275 275/4.1	90	4(-7)
Teflon FEP (40 mil) Die A Specimen	0	0 (control specimens)	0	0		—	—	1860 198[illegible] 1886 1983 1915 1906/58	1906 2009 1910 1932 1943 1940/44	1930 2009 1933 1932 1971 1955/34	2930 2583 2641 2704 2728 2717/149	385 325 345 350 330 347/26	—	—
	1.5(8)	3.3(12) (air irradiation)	3.0(13)	[illegible]	16	—	—	1822 1714 1886 1768 1792 1796/74	1869 1835 1510 1816 1839 1854/40	1845 1835 1886 1792 1674 1806/91	2102 2202 2311 2122 2216 2191/90	300 320 320 300 325 313/11	80	—
	5.8(8)	2.4(13) (air irradiation)	1.2(14)	4.9(12)	16	—	—	2065 1904 1913 2105 1913 [illegible]	2085 1928 1913 2105 1937 1994/83	2065 1657 — 1913 18[illegible] 1931/101	2276 1928 1913 2009 2081 2041/156	120 100 55 110 110 99/28	82	—

TABLE A-12. (Continued)

Material Trade Name	Gamma [ergs/gm(C)]	Neutron (n/cm²) Thermal	Neutron E>2.9 Mev	Neutron E>8.1 Mev	Time Until Test, days	Sample Weights Original, gm	Sample Weights Change, gm	Tensile Strength* (psi) at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press. Avg., torr
	9.1(7)	7.8(12) (vacuum irradiation)	1.7(13)	7.0(11)	8	5.4242 5.4134 5.4191 5.3782 5.4175	+0.0007 +0.0014 +0.0031 +0.0022 -0.0030	1886 1941 1908 1908 1886 1906/24	1933 1966 1956 1932 1933 1944/15	1933 1975 1956 1956 1933 1951/18	2452 2584 2318 2294 2487 2422/99	320 315 305 310 330 316/11	80	1.7(-7)
	3.9(8)	1.9(13) (vacuum irradiation)	4.4(13)	1.7(12)	7	5.3818 5.3837 5.4215 5.4641 5.4292	-0.0007 +0.0004 0.0000 -0.0005 -0.0006	1849 1893 1917 1893 1870 1884/29	1867 1922 1941 1893 1899 1904/32	1887 1922 1941 1932 1889 1914/23	2231 2246 2427 2294 1889 2217/231	330 315 355 336 100 287/110	90	4(-7)
Tedlar (2 mil)	0	0 (control specimens)	0	0		—	—	5900 5750 5750 6000 5750 5830/107	6150 5750 5750 6000 5900 5910/172	—	9900 9250 9650 9350 9150 9460/322	245 227 276 255 230 247/22	—	—
	1.5(8)	3.3(12) (air irradiation)	3.0(13)	1.1(12)	12	—	—	5250 5500 5500 5650 5477/172	5400 5350 5400 5650 5450/129	5750 5500 5400 5650 5575/150	8350 8550 8430 8650 8618/451	255 280 260 250 261/13	80	—
	1.36(9)	1.8(13) (air irradiation)	2.5(14)	9.5(14)	12	—	—	5350 5650 5750 5250 5400 5470/215	5350 5750 5750 5350 5400 5520/172	5400 5750 5650 5500 5500 5600/193	7650 7750 8700 8400 8000 8020/023	190 225 260 230 260 233/30	82	—
	9.1(7)	7.8(12) (vacuum irradiation)	1.7(13)	7.0(11)	9	0.3186 0.3178 0.3175 0.3182 0.3168	+0.0004 0.0000 -0.0099 +0.0002 +0.0004	6000 6250 6100 6250 5900 6100/150	6250 — 5750 — 6000 6000/29	6500 — — — 6150 6325/x	10000 7500 10400 9650 10250 9560/1247	260 — 285 220 320 271/49	80	1.7(-7)
	4.45(8)	1.95(13) (vacuum irradiation)	5.45(13)	2.1(12)	8	0.3218 0.3162 0.3250 0.3179 0.3132	-0.0008 +0.0003 +0.00[illegible] +0.00[illegible] +0.0002	— 5800 6100 [illegible] [illegible] 61[illegible]/267	— 5800 6150 6150 6000 6025/170	— — — — 6250 —	— 9100 9650 9300 9650 942[illegible]/267	225 218 240 240 250 235/14	90	4(-7)

TABLE A-12. (Continued)

Material Trade Name	Gamma [ergs/gm(C)]	Radiation Exposure: Neutron (n/cm²) Thermal	E>2.9 Mev	E>8.1 Mev	Time Until Test, days	Sample Weight: Original, gm	Change, gm	Tensile Strength* (psi): at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press Avg., torr
	9.4(8)	2.8(13) (vacuum irradiation)	1.5(14)	5.6(12)	8	0.3126 0.3135 0.3249 0.3225 0.3242	-0.0001 [illegible] [illegible] 0.0003 -0.0002	— 5900 6150 6000 6250 6075/170	5750 5900 6150 6100 6400 6060/279	5900 — 6250 6150 — 6100/207	9000 8850 8850 8650 9600 8990/408	235 220 225 220 240 228/9	90	4(-7)
B-film (2 mil)	0	0 (control specimens)	0	0		—	—	14661 14237 14407 15678 14492 15339 — — 14802/569	15593 15339 15678 15610 15254 16186 15085 15085 15604/536	18475 17627 18305 19322 17542 19068 17966 15847 18019/1221	20678 19068 19407 20508 18644 20339 17966 19157 19470/[illegible]	140 120 125 140 140 130 100 128 128/14	—	—
	6.0(9)	(air irradiation)	1.26(15)		16	—	—	15169 [illegible]831 [illegible]61 [illegible]254 15424 15008/328	15678 15254 15678 16102 16102 15763/365	—	16356 17797 18729 20508 20508 18780/1785	— 110 115 135 130 123/12	100	—
	3.9(10)	2.8(14) (air irradiation)	6.1(15)	2.6(14)	16	—	—	15678 15678 15085 15424 15466/268	16610 16525 15932 16441 16377/329	— — — 18729 18729	17458 17288 18136 18729 17903/700	65 60 105 100 83/22	100	—
	1.05(10)	1.[illegible](14) (vacuum irradiation)	1.65(15)	5.9(13)	11	—	—	14831 14831 14831 14254 14937/205	16017 15847 15593 16102 15890/247	—	16949 20339 19492 21102 19871/2017	90 135 125 138 122/25	150	1(-3)
	2.85(10)	3.68(14) (vacuum irradiation)	6.62(15)	2.09(14)	10	0.1352 0.1464 0.1420 0.1401 0.1373	0.0000 -0.0015 -0.0003 -0.0009 -0.0001	15169 — — 15000 14576 14915/350	15932 — — 16016 16355 16101/250	—	15932 19492 18898 21186 18877/2552	50 — 120 105 135 103/41	200	6(-7)
Thermofit	0	0 (control specimens)	0	0				1768 1430 1531 1571 1724 1720 1624/133	1763 1470 1531 1598 1724 1720 1635/118	1632 1403 1497 1543 1594 1633 1550/91	2755 2510 2039 2811 2700 2667 2613/327	400 390 — 395 395 425 401/15	—	—

TABLE A-12. (Continued)

Material Trade Name	Radiation Exposure: Gamma [ergs/gm(C)]	Neutron (n/cm²): Thermal	Neutron (n/cm²): E>2.9 Mev	Neutron (n/cm²): E>8.1 Mev	Time Until Test, days	Sample Weights: Original, gm	Sample Weights: Change, gm	Tensile Strength* (psi): at 25% Elongation	Tensile Strength* (psi): at 50% Elongation	Tensile Strength* (psi): at 100% Elongation	Tensile Strength* (psi): Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press. Avg., torr
	1.5(8)	3.3(12) (air irradiation)	3.0(13)	1.1(12)	13			1515 1422 1593 1562 1510 1520/74	1534 1476 1593 1562 1530 1531/50	1469 1386 1472 1477 1428 1447/38	2482 2493 2630 2463 2707 2555/105	410 360 390 400 410 394/21	80	—
	1.36(9)	1.8(13) (air irradiation)	2.5(14)	9.5(12)	13			1658 1606 1626 1652 1633 1639/22	1711 1636 1646 1704 1686 1670/31	1579 1540 1558 1573 1587 1567/20	2139 3770 1944 2327 2624 2561/785	270 230 250 290 290 266/26	82	—
	1.07(9)	1.9(14)	2.3(15)	8.2(13)	16			2100 — — 2054 — 2077/27	—	—	2100 2114 1970 2054 2080 2064/62	25 30 20 25 35 27/6	100	—
	1.8(8)	8.4(12) (vacuum irradiation)	1.85(13)	7.6(11)	8	3.2179 3.2633 3.2278 3.1546 3.3521	+0.0012 +0.0019 +0.0018 +0.0019 +0.0017	1673 1673 1700 1533 — 1651/50	1673 1693 1700 1618 — 1671/35	1572 1572 1666 1548 — 1590/51	2744 2844 2496 2885 2763 2746/167	400 400 370 400 395 393/13	80	1.7(-7)
	8.8(9)	2.8(13) (vacuum irradiation)	1.7(14)	6.4(12)	7	3.1783 3.2308 3.0910 3.1378 3.3332	+0.0006 +0.0007 +0.0007 +0.0002 +0.0001	1722 1646 1716 1626 1683 1679/41	1736 1680 1743 1654 1683 1699/38	1682 1653 1702 1640 1645 1664/27	2646 2413 2802 2853 2784 2700/189	325 315 322 322 335 324/9	90	4(-7)
	1.3(10)	1.2(15) (vacuum irradiation)	2.0(15)	9.8(13)	6	3.2961 3.1984 3.2143 3.2038 3.3051	-0.1191 -0.0792 -0.1025 -0.0954 -0.1472	1807 — 1800 — 1800 1802/4	—	—	2115 2106 2053 2101 2120 2099/29	35 65 50 45 45 48/13	160	3(-7)
Teflon TFE (40 mil)	0	0 (control specimens)	0	0				[illegible] [illegible] [illegible] 1194/34.8	1683 1690 1660 1678/17.7	— 1767 1762 1764/4.4	— 1881 1585 2733/254	— 290 315 302/22.1**	77	760

TABLE A (Continued)

Material Trade Name	Radiation Exposure: Gamma [ergs/gm(C)]	Neutron (n/cm²): Thermal	Neutron (n/cm²): E>2.9 Mev	Neutron (n/cm²): E>8.1 Mev	Time Until Test, days	Sample Weights: Original, gm	Sample Weights: Change, gm	Tensile Strength** (psi): 25% Elongation	Tensile Strength** (psi): at 50% Elongation	Tensile Strength** (psi): at 100% Elongation	Tensile Strength** (psi): Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press. Avg., torr
	1.9(9)	6.7(12) (vacuum irradiation)	2.9(13)	8.0(11)		8.7099 8.7756 8.8495 9.0502	-0.0003 +0.0012 0.0000 -0.0001	—	—	—	1564 1512 1481 1519/49.0	15 5 15 11.7/5.9	80	5(-6)
Teflon TFE (10 mil)	0	0 (control specimens) August 1962	0	0				1630 1690 1670 1670 1665/29.1	1750 1840 1800 1800 1798/43.7	1970 2050 1930 1990 1985/58.3	2230 2130 2120 2280 2202/7[illegible]	155 116 139 148 140/18.0	77	760
	0	0 (control specimens) February 1963	0	0	—			1620 1580 1780 1660/118	1800 1800 1950 1850/88.6	— 2110 2180 2145/62.1	2240 2210 2300 2250/53.2	160 125 130 138/20.7	—	—
	0	0 (vacuum controls) February 1963	0	0		2.1280 2.0628 2.0423 2.1156 2.1127	+0.0002 +0.0002 +0.0008 +0.0011 +0.0004	— 1660 1711 1680 1660 1663/53.4	— 1820 1875 1870 1850 1854/26.7	— 2070 2130 2070 2080 2088/29.1	— 2180 2260 2280 2220 2235/48.6	— 130 132 137 120 130/8.3	77 77	1(-6)
	1.7(9)	6.5(12) (vacuum irradiation)	1.9(13)	7.3(11)		2.1373 2.1778 2.1397 2.0991	-.0023 0.0000 -0.0002 +0.0032	—	—	—	1300 1250 — — 1275/44.3	2 3 — — 2.5/0.89	80***	5(-6)
Teflon 100 (40 mil)	0	0 (control specimens)	0	0		—	—	1690 1725 1725 1713/20.7	1750 1770 1770 1763/11.8	1775 1800 1805 1793/17.7	2108 1910 2165 2061/151	283 235 268 262/28.4	77	760
	8.6(9)	3.7(14) (vacuum irradiation)	3(15)	4.6(13)		8.2465 8.1375 8.1265	-0.0250 -0.0187 -0.0197	—	—	—	1307 1141 1224/73.6	2 1 1.5/0.89	110	5(-7)
Marlex 6002 (polyethylene)	0	0 (control specimens)	0	0		—	—	—	—	—	4143 3857 3929 4214 3571 3929 3941/254	>(800)**** >(800)**** >(800)**** >(800)**** 1060 950 1305/97.5	77	760

TABLE A-12. (Continued)

Material Trade Time	Radiation Exposure: Gamma [ergs/gm(C)]	Neutron (n/cm²) Thermal	Neutron E>2.9 Mev	Neutron E>8.1 Mev	Time Until Test, days	Sample Weights: Original, gm	Sample Weights: Change, gm	Tensile Strength* (psi): at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press. Avg., torr
	1.1(10)	3.6(14) (vacuum irradiation)	1.3(15)	5.5(13)		1.2836 1.2862 1.2548	-0.0006 -0.0004 -0.0007	—	—	—	5429 5500 5286 5405/120	50 75 40 55/20.7	114	5(-7)
Teslar	0	0 (control specimens)	0	0		—	—	6050 6100 6250 6215 5950 6113/129	6100 6100 6500 6375 6090 6233/176	6700 6800 7500 — — 7000/472	9100 — 7500 7200 6765 7641/1134	170 — 100 90 78 110/44.7	77	760
	1.3(9)	6.1(12) (vacuum irradiation)	1.55(13)	5.95(11)		0.3060 0.3060 0.2967 0.3095 0.3050	+0.0005 +0.0005 +0.0009 +0.0005 +0.0004	—	—	—	7650 8150 8100 7800 7925/243	90 105 105 105 101/7.3	100	5(-6)
	6.2(9)	8.6 (vacuum irradiation)	9.1(13)	3.4(12)		0.2914 0.2872 0.2810 0.3050	+0.0001 -0.0002 +0.0001 -0.0005	—	—	— *****	7900 6800 9000 7500 7800/1008	90 70 100 75 84/14.5	100	5(-6)

* Values given : s: average value/standard deviation on an individual basis.

** Average value/standard deviation on an individual basis.

*** Estimated value based on temperature of Teflon (40 mil)

**** The elongation was greater than 800 percent but was not the ultimate, since the original gage length selected for this specimen was too large and resulted in an insufficient amount of total crosshead travel required to break the specimen. This did not effect the maximum strength, however, since this value is obtained when the specimen yields.

***** Specimen broke in jaws.

Tested under atmospheric conditions.

TABLE A-13. TENSILE STRENGTH OF DYNALAM LAMINATES(1)

	Exposure			Tensile Strength**, psi		
Type*	Gamma, ergs g^{-1}(C)	Neutron, n cm^{-2} (E>2.9)	Irrad. Temp, F	Sheet 1	Sheet 2	
A	Controls	Controls	75	39,411/4,528/6	31,163/2,453/8	/8
A	5.6×10^{10}	5.2×10^{15}	120	36,894/6,650/5	29,372/2,26[illegible]/5	/5
A	1.7×10^{11}	1.7×10^{16}	130	38,317/3,082/5	29,559/1,258/5	/5
A	Controls	Controls	450	[illegible]1,157/7,724/5	20,[illegible]/5,226/5	/5
A	[illegible] $\times 10^{10}$	7.2×10^{15}	455	28,160/3,494/5	22,[illegible]0/1,826/5	/5
B	Controls	Controls	75	40,073/8,633/5	32,080/4,173/3	/3
B	5.6×10^{10}	5.2×10^{15}	120	44,047/4,184/4	32,706/4,870/5	/5
B	1.7×10^{11}	1.7×10^{16}	130	41,297/11,674/4	31,563/3,502/5	/5
B	Controls	Controls	450	30,822/2,988/3	21,962/2,735/5	/5
B	6.0×10^{10}	7.2×10^{15}	455	30,684/4,995/4	21,252/3,953/5	/5

*A - with curing agent
B - without curing agent.

**Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of an [illegible] observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

TABLE A-14. EFFECT OF TEMPERATURE AND VACUUM ON LAMINATES(9)

Laminate	Test Conditions		Tests	Test Result	Comments
1. Epon 828, Het anhydride cured, fiberglas cloth	Temperature Pressure Time at pressure	400 F 8.3×10^{-5} 6 hours	Wet compression test at room temperature	2.6% Increase in compression strength	--
2. Polyester, 181 glass cloth with Volan A finish	Temperature Pressure Time at pressure	250 F 1.0×10^{-4} 6 hours	Ditto	8.4% Increase	--
3. Phenolic 91LD, 181 glass cloth with Volan A finish	Temperature Pressure Time at pressure	400 F 4.5×10^{-4} 4.5 hours	"	36.5% Increase	--
4. Silicone phenolic 37-9X, 181 glass cloth with Volan A finish	Temperature Pressure Time at pressure	400 F 4.4×10^{-4} 6 hours	"	9.6% Increase	Compression data widely scattered
5. Epon X131, on 181 glass cloth with Volan A finish	Temperature Pressure Time at pressure	400 F 2.2×10^{-4} 6 hours	"	No significant change	--
6. Silicone R 7141 asbestos	Temperature Pressure Time at pressure	400 F 6.5×10^{-5} 2.5 hours	"	3.7% Increase	Compression data widely scattered
7. DC 2103 Silicone asbestos RPI	Temperature Pressure Time at pressure	400 F 1.1×10^{-4} 6.5 hours	"	4.1% Decrease	Compression data widely scattered
8. Melamine A1100, 181 glass cloth with Volan A	Temperature Pressure Time at pressure	400 F 9.6×10^{-5} 6 hours	"	5.2% Decrease	Ditto
9. Phenolic 41RPD, asbestos	Temperature Pressure Time at pressure	400 F 4.3×10^{-4} 5.5 hours	"	6.1% Increase	"

TABLE A-15. COMPOSITION OF PLASTIC TEST SPECIMENS[7]

Specimen	Description	Material Trade Name	Manufacturer
1	Epoxy with unidirectional glass fibers	Scotchply 1009-26	3M Company
2	Phenolic with glass fabric - lengthwise	Type 143 glass fabric, SC 1008 resin	Coast Mfg.
3	Phenolic with high-silica fabric	Refrasil fabric, SC 1008 resin	Western Backing
4	Phenolic with asbestos felt - random	40 RPD asbestos, Plyophen 5900 resin	U.S. Polymeric
5	Phenolic with graphite fabric!	Graphite fabric, SC 1008 resin	Coast Mfg.
6	Phenolic with chopped glass fibers - random	Molding Compound OPX-197	Fiberite
7	Phenolic with chopped glass fibers - random	Molding Compound MX-2625	Fiberite
8	Phenolic with chopped graphite fabric random	Molding Compound MX-4551	Fiberite
9	Phenyl-silane with glass fabric	Type 181 glass fabric, SC 1013 resin	Monsanto
10	Epoxy with glass fabric	Type 181 glass fabric, E-787 resin	U.S. Polymeric

TABLE A-16. SUMMARY OF PROPERTY CHANGES FOR MATERIALS IRRADIATED IN VACUUM AND AIR AND TESTED IN AIR(6)

Category	Material Trade Name	Gamma Exposure, ergs/gm(C)	Vacuum (torr)	Specimen Configuration	Measured Property	Change in Measured Property, per cent
Structural Laminates	Silicone DC-2106	4.5×10^{10}	5×10^{-7}	Tensile (ASTM-D-638-58T, Type I)	Ultimate tensile strength Ultimate elongation Weight Change	0 0 -0.19
	CTL-91-LD (phenolic)	4.5×10^{10}	5×10^{-7}	Tensile (ASTM-D-638-58T, Type I)	Ultimate tensile strength Ultimate elongation Weight change	0 0 -0.60
	Epon 828 (epoxy)	8.6×10^{9}	3×10^{-1}	Tensile, modified (ASTM-D-638-58T Type I)	Ultimate tensile strength Ultimate elongation	0 0
		7.5×10^{9}	3×10^{-7}	Straight flexural specimens	Ultimate flexural strength Ultimate deflection Weight change	0 0 0
	Conolon 506 (phenolic)	9.7×10^{9}	3×10^{-1}	Tensile, modified (ASTM-D-638-58T, Type I)	Ultimate tensile strength Ultimate elongation	0 0
	Mobiloy AH-81 (phenolic)	1.7×10^{10}	5×10^{-7}	Straight tensile specimens	Ultimate tensile strength	-15.6

TABLE A-17. SUMMARY OF PROPERTY CHANGES FOR MATERIALS IRRADIATED AND TESTED IN VACUUM(6)

Category	Material Trade Name	Gamma Exposure [ergs/gm(C)]	Vacuum (torr)	Specimen Configuration	Measured Property	Change in Measured Property, per cent
Adhesive	FM-1000 (epoxy polyamide)	1.1×10^{10}	3×10^{-1}	Lap shear, modified	Ultimate shear strength	0
		1.9×10^{10}	5×10^{-6}	Lap shear, modified	Ultimate shear strength	+21
	MB-302 (epoxy phenolic)	1.6×10^{10}	3×10^{-1}	Lap shear, modified	Ultimate shear strength	+15
		2.1×10^{10}	5×10^{-6}	Lap shear, modified	Ultimate shear strength	+41.5
Structural Laminate	Conolon 506 (phenolic)	1.3×10^{10}	3×10^{-1}	Tensile, modified (ASTM-D-638-58T)	Ultimate tensile strength	+29.6
					Ultimate elongation	+50
		2.0×10^{10}	5×10^{-6}	Tensile, modified (ASTM-D-638-58T)	Ultimate tensile strength	+ 55
	Epon 828/A (epoxy)	1.4×10^{10}	3×10^{-1}	Tensile, modified (ASTM-D-638-58T)	Ultimate tensile strength	+27
					Ultimate elongation	+43
		2.0×10^{10}	5×10^{-6}	Tensile, modified (ASTM-D-638-58T)	Ultimate tensile strength	+48
Seal	Viton F (PRP 19007)	9.0×10^{9}	3×10^{-7}	O-Rings	Ultimate tensile strength	+7
					Ultimate elongation	-79
Potting Compound	RTV-60 (silicone)	8.6×10^{9}	3×10^{-7}	Compression disks	Compressive strength at 0.02-inch deflection	+76
Thermal Insulation	Stafoam AA-402 (polyurethane)	8.9×10^{9}	3×10^{-7}	Compression disks	Compressive strength at 25% deflection	+30
					Ultimate compressive strength	+22
					Weight change	-2.0

TABLE A-18. TEST ENVIRONMENTS AND RESULTS OF STATIC TESTS: STRUCTURAL LAMINATES

Material Trade Name	Radiation Exposure: Gamma [ergs/gm(C)]	Neutrons (n/cm^2): Thermal	Neutrons (n/cm^2): $E>2.9$ Mev	Neutrons (n/cm^2): $E>8.1$ Mev	Time Until Test, days	Sample Weight: Original, grams	Sample Weight: Change, grams	Ultimate Tensile Strength, psi	Ultimate Elongation, per cent	Temperature Average, °F	Pressure Average, torr
Mobiloy 81-AH7 (phenolic)	0	0	0	0	-	-	-	60866	1.96	-	-
		(control specimens)						41245	1.46		
								38717	1.30		
								54123	1.60		
								49238/10757	1.60/0.32		
	6.0(9)	-	1.26(15)	-	14	-	-	60082	1.75	100	-
		(air irradiation)						45238	1.44		
								46746	1.37		
								38716	1.75		
								41122	1.30		
								46381/9186	1.52/0.19		
	1.07(10)	1.9(14)	2.3(15)	8.2(13)	14	-	-	49705	1.53	100	-
		(air irradiation)						59153	1.86		
								42082	1.36		
								39289	1.18		
								56672	1.75		
								49380/8540	1.54/0.29		
	3.9(10)	2.[illegible](14)	6.1(15)	2.6(14)	14	-	-	47199	1.57	100	-
		([illegible] irradiation)						54313	1.81		
								50329	1.56		
								50385	1.61		
								34615	1.02		
								47368/8469	1.51/0.34		
	4.1(9)	6.4(13)	3.7(14)	1.6(13)	6	15.1895	-0.0300	47750	1.37	160	8(-7)
		(vacuum irradiation)				15.2567	-0.0261	58373	1.77		
						14.8518	-0.0206	55652	1.71		
						[illegible]	-0.0231	60949	1.88		
						[illegible]	-0.0275	56568	1.44		
								55838/5675	1.63/0.22		

TABLE [illegible]18. (Continued)

Material Trade Name	Radiation Exposure: Gamma [ergs/gm(C)]	Neutrons (n/cm^2): Thermal	Neutrons (n/cm^2): E>2.9 Mev	Neutrons (n/cm^2): E>8.1 Mev	Time Unt[illegible] T[illegible]t, days	Sample Weight: Original, grams	Sample Weight: Change, grams	Ultimate Tensile Strength[a], psi	Ultimate Elongation[a], per cent	Temperature Average, °F	Pressure Average, torr
	1.4(10)	9.5(14) (vacuum irradiation)	1.8(15)	7.4(13)	6	15.0600	-0.0241	61167	1.50	160	8(-7)
						14.6719	-0.0287	57673	1.63		
						14.6645	-0.0218	58771	1.29		
						14.6314	-0.0194	60832	1.61		
						14.7718	-0.0272	55264	1.54		
								58741/2538	1.51/0.15		
	3.1(10)	2.87(14) (vacuum irradiation)	7.87(15)	-	13	15.2639	-0.0151	39535	1.05	200	6(-7)
						14.6430	+0.0077	46400	1.50		
						14.3558	+0.0101	--	-		
						14.5942	+0.0079	--	-		
						14.9385	+0.0103	41016	1.19		
								42317/4055	1.25/0.27		
Paraplex P-43 (polyester)	0	0 (control specimens)	0	0	-	-	-	37925	1.61	-	-
								35042	1.78		
								38738	1.78		
								38529	1.94		
								37638	2.02		
								43650	2.15		
								41117	1.75		
								40140	2.17		
								40815	1.75		
								3813[illegible]	1.88		
								39173/2767	1.88/0.18		
	6.0(9)	- (air irradiation)	1.26(15)	-	15	-	-	36322	1.77	100	-
								35611	1.75		
								26891	1.45		
								32941/5571	1.66/0.19		
	1.07(10)	1.9(14) (air irradiation)	2.3(15)	8.2(13)	15	-	-	40862	1.87	100	-
								39299	1.95		
								25249	1.10		
								36370	1.61		
								[illegible]5445/7587	1.63/0.41		

TABLE A-18. (Continued)

Material Trade Name	Radiation Exposure: Gamma [ergs/gm(C)]	Neutrons (n/cm²): Thermal	Neutrons (n/cm²): E>2.9 Mev	Neutrons (n/cm²): E>8.1 Mev	Time Until Test, days	Sample Weight: Original, grams	Sample Weight: Change, grams	Ultimate Tensile Strength,[a] psi	Ultimate Elongation,[a] per cent	Temperature Average, °F	Pressure Average, torr
	3.9(10)	2.8(14) (air irradiation)	6.1(15)	2.6(14)	15	-	-	36103 36114 36075 38799 36773/1324	1.89 1.79 1.73 1.80 1.80/0.08	100	-
	4.1(9)	6.4(13) (vacuum irradiation)	3.7(14)	1.6(13)	6	14.6953 14.5378 14.5011 13.7559	-0.0119 -0.0143 -0.0172 -0.0142	40348 40898 40126 49698 42768/4652	1.88 1.92 2.00 1.94 1.94/0.06	160	8(-7)
	1.4(10)	9.4(14) (vacuum irradiation)	1.8(15)	7.4(13)	9	14.0466 13.5526 14.7077 14.8699	-0.0278 -0.0252 -0.0401 -0.0368	40523 43224 39366 38311 40356/2338	1.65 2.06 1.96 1.86 1.88/0.17	160	8(-7)
	3.1(10)	2.87(14) (vacuum irradiation)	7.87(15)	-	12	14.8013 12.9719 14.8986 13.7477	-0.1001 -0.0735 -0.1199 -0.1060	31250 35871 28908 31603 31908/3384	1.52 1.54 1.44 1.62 1.53/0.09	200	6(-7)
DC-2104 (silicone)	0	0 (control specimens)	0	-	-	-	-	16359 21626 23210 17848 17989 19406/2945	0.94 1.17 1.11 1.10 0.93 1.05/0.10	-	-

TABLE A-19. (Continued)

Material Trade Name	Radiation Exposure: Gamma ergs/gm(C)	Neutrons (n/cm²): Thermal	Neutrons (n/cm²): E>2.9 Mev	Neutrons (n/cm²): E>8.1 Mev	Time Until Test, day	Sample Weight, grams	Weight Change, grams	Ultimate Tensile Strength,[a] psi	Ultimate Elongation,[a] per cent	Temperature Average, °F	Pressure Average, torr
DC-2104 (silicone)	6.0(9)	-	1.26(15)	-	14	-	-	17562	0.95	100	-
		(air irradiation)						17594	0.89		
								21192	1.09		
								20131	1.07		
								26094	1.23		
								20515/3668	1.05/0.15		
	1.07(10)	1.9(14)	2.3(15)	8.2(13)	14	-	-	19352	1.02	100	-
		(air irradiation)						20645	1.07		
								19789	1.04		
								18707	1.05		
								18622	0.91		
								19423/870	1.02/0.07		
	3.9(10)	2.8(14)	6.1(15)	-	14	-	-	19737	1.16	100	-
		(air irradiation)						22795	1.19		
								21080	1.23		
								19768	1.15		
								20290	1.12		
								20734/1315	1.17/0.05		
	3.8(9)	-	3.6(14)	1.5(13)	6	19.8010	-0.0691	22243	1.19	160	8(-7)
		(vacuum irradiation)				13.4341	-0.0450	19512	1.50		
						13.8041	-0.0459	19073	1.34		
						20.3603	-0.0416	23438	1.25		
						20.1233	-0.0658	21229	1.14		
								21099/1877	1.28/0.15		
	1.4(10)	9.4(14)	1.8(15)	7.4(13)	6	20.0366	-0.0720	22946	1.17	160	8(-7)
		(vacuum irradiation)				20.3746	-0.1400	19199	1.21		
						20.3654	-0.1305	20392	1.21		
						20.3454	-0.0711	23198	1.17		
						19.9027	-0.1136	22365	1.25		
								218.0/2041	1.20/0.03		
	2.85(10)	3.88(14)	6.62(15)	2.09(14)	12	20.3202	-0.2352	16022	0.98	200	6(-7)
		(vacuum irradiation)				19.4871	-0.2169	16346	1.10		
						20.4845	-0.2492	17755	1.14		
						20.1397	-0.2480	14991	0.97		
						20.3301	[illegible]	16887	1.11		
								16400/1184	1.06/0.07		

TABLE A-18. (Continued)

Material Trade Name	Radiation Exposure: Gamma [ergs/gm(C)]	Neutrons (n/cm^2): Thermal	Neutrons (n/cm^2): E>2.9 Mev	Neutrons (n/cm^2): E>8.1 Mev	Time Until Test, days	Sample Weight: Original, grams	Sample Weight: Change, grams	Ultimate Tensile Strength,[a] psi	Ultimate Elongation,[a] per cent	Temperature Average, °F	Pressure Average, torr
Selectron 5003 (polyester)	0	0 (control sr	0	0	-	-	-	45524 45768 50593 42829 45429/3800	1.93 1.52 2.13 2.28 1.99/0.32	-	-
	6.0(9)	- (air irradiation)	1.26(15)	-	14	-	-	50444 51102 48217 46602 42661 47805/3629	1.94 2.04 1.63 1.84 1.84 1.86/0.18	100	-
	1.07(10)	1.9(14) (air irradiation)	2.3(15)	8.2(13)	14	-	-	35878 41609 48819 40637 42452 41879/5564	1.43 1.64 2.00 1.78 1.60 1.39/0.25	100	-
	3.9(10)	2.8(14) (air irradiation)	6.1(15)	2.6(14)	14	-	-	41767 50020 43998 48033 45256 45815/3548	1.86 1.90 1.84 1.62 1.71 1.79/0.12	100	-
	7.2(9)	1.29(14) (vacuum irradiation)	6.55(14)	2.45(13)	15	-	-	52038 55585 56102 47905 51655 52657/3524	2.02 2.13 2.19 1.62 2.29 2.05/0.29	130	1(-3)

TABLE A-18. (Concluded)

Trade Name	Radiation Exposure: Gamma ergs/gm(C)	Neutrons (n/cm²): Thermal	Neutrons (n/cm²): E>2.9 Mev	Neutrons (n/cm²): E>8.1 Mev	Time Until Test, days	Sample Weight: Original, grams	Sample Weight: Change, grams	Ultimate Tensil Strength,[a] psi	Ultimate Elongation,[a] per cent	Temperature Average °F	Pressure Average, torr
Selectron 5003 (polyester)	1.05(10)	1.32(14) (vacuum irradiation)	1.65(15)	5.90(13)	13	-	-	51918	2.36	150	1(-3)
								46924	1.45		
								42609	2.03		
								44120	2.09		
								44830	1.94		
								46080/4002	1.97/0.39		
	2.85(10)	3.88(14) (vacuum irradiation)	6.62(15)	2.09(14)	12	-	-	45782	1.83	200	6(-7)
								50814	2.03		
								40864	1.96		
								42293	1.96		
								44176	1.81		
								44786/4278	1.92/0.09		

Tested under atmospheric conditions.

(a) Values given as average value/standard deviation on an individual basis.

TABLE A-19. TEST ENVIRONMENTS AND RESULT OF STATIC TESTS: STRUCTURAL LAMINATES(7)

Material Trade Name	Radiation Exposure: Gamma [ergs/gm(C)]	Radiation Exposure: Neutrons (n/cm²) Thermal	Radiation Exposure: Neutrons (n/cm²) E>2.9 Mev	Radiation Exposure: Neutrons (n/cm²) E>8.1 Mev	Time Until Test, days	Compressive Strength at 25% Elongation, psi	Compressive Elongation,[a] per cent	Temperature Average, °F	Pressure Average, torr
Honeycomb HRP (phenolic)	0	0 (control specimens)	0	0	-	303 302 276 330 303/26	422 438 418 441 427/16	-	-
	6.0(9)	- (air irradiation)	1.26(15)	-	23	-	431 494 456 460/37	100	-
	1.07(10)	1.9(14) (air irradiation)	2.3(15)	8.2(13)	23	-	606 567 606 531 578/36	100	-
	3.9(10)	2.8(14) (air irradiation)	6.1(15)	2.6(14)	23	-	582 625 544 462 468 536/27	100	
	5.9(9)	1.18(14) (vacuum irradiation)	6.56(14)	-	23	280 352 282 305/43	424 447 422 431/15	150	1(-3)

TABLE A-19. (Concluded)

Material Trade Name	Radiation Exposure: Gamma ergs/gm(C)	Neutrons (n/cm²): Thermal	Neutrons (n/cm²): E>2.9 Mev	Neutrons (n/cm²): E>8.1 Mev	Time Until Test, days	Compressive Strength at 25% Elongation, psi	Compressive Elongation,[a] per cent	Temperature Average °F	Pressure Average torr
Honeycomb HRP (phenolic)	1.05(10)	1.32(14) (vacuum irradiation)	1.65(15)	5.9(13)	23	-	456 433 446/22	150	1(-3)
	2.85(10)	3.88(14) (vacuum irradiation)	6.62(15)	2.09(14)	22	-	483 410 482 458/43	200	6(-7)

Tested under atmospheric conditions.

(a) Values given as average value/standard deviation on an individual basis.

TABLE A-20. FLEXURAL STRENGTH OF LAMINATES AFTER EXPOSURE TO VACUUM AND VARIED INTENSITY[35] OF ULTRAVIOLET RADIATION[35]

Radiation Falling on Specimens, pyrons	Time of Exposure, hours	Average* Ultimate Flexural Strength, psi	Average* Flexural Modulus x 10^6, psi
		Polyester P-43 Laminate	
Control	0	59,300	2.4
2	125	61,800	2.6
3	125	64,400	2.8
4	25	50,100	2.5
5	3	24,200	-
6	3	--	-
		Epoxy Epon 815 Laminate	
0	0	84,400	3.8
2	125	84,700	3.8
3	125	84,000	3.8
4	25	57,600	3.5
5	3	39,800	-
6	3	--	-
		Phenolic CTL-91 Laminate	
0	0	68,900	3.6
2	125	61,700	3.6
3	125	56,700	3.5
4	25	49,500	3.0
5	3	57,100	3.2
6	3	--	-

* Average of four specimens.

TABLE A-21. COMPRESSIVE STRENGTH OF LAMINATES AFTER EXPOSURE TO VACUUM AND VARIED INTENSITY OF ULTRAVIOLET RADIATION[35]

Radiation Falling on Specimens, pyrons	Time of Exposure, hours	Average* Compressive Strength, psi	Average* Compressive Modulus x 10^6, psi
	Polyester P-43 Laminate		
Control	0	40,900	3.1
2	125	47,300	3.1
3	125	51,900	3.2
4	25	40,800	3.1
5	3	39,900	3.1
6	3	--	-
	Epoxy Epon 815 Laminate		
0	0	53 900	3.5
2	125	48,400	3.5
3	125	51,300	3.5
4	25	43,800	3.4
5	3	44,200	3 4
6	3	--	-
	Phenolic CTL-91 Laminate		
0	0	44,800	3.5
2	125	39,400	3.5
3	125	39,300	3.5
4	25	31,500	3.4
5	3	32,600	3.4
6	3	--	-

* Average of four specimens.

TABLE A-22. LAMINATE PANELS PREPARED WITH ULTRAVIOLET ABSORBERS(19)

Panel	Reinforcement	Resin	Catalyst	Ultraviolet Absorber by Weight Based on Resin	Laminate Thickness	Resin Yellowing Due to UV Absorber	Appearance of Panel
UV I	12 plies 181-172	Paraplex P-444A	1% B.P.	None added	0.105	None	Opaque
UV II	12 plies 181-172	P-43	1% B.P.	0.5% Cyasorb UV9	0.109	None	Transparent
UV III	12 plies 181-172	P-43	1% B.P.	0.5% Cyasorb UV24	0.112	Slight	Transparent
UV IV	12 plies 181-172	P-43	1% B.P.	Geigy Tunuvin P CH3497 0.5%	[illegible]	Slight	Transparent
UV V	12 plies 181-172	P-43	1% B.P.	Dicarboxy-ferrocene 0.1%	0.110	Decided yellowing	Opaque

TABLE A-23. PERCENTAGE LOSS IN WEIGHT OF POLYESTER LAMINATES CONTAINING ULTRAVIOLET-ABSORBING AGENTS(19)

Panel	Control	Ultimate Flexural Strength* After Indicated Exposure, psi				
		2 pyrons 100 hours	2 pyrons 200 hours	3 pyrons 100 hours	3 pyrons 125 hours	6 pyrons 6 hours
UV I	61,000	70,400	72,500	72,500	72,800	56,700
UV II	78,800	81,400	82,500	79,500	80,500	72,300
UV III	72,400	76,400	80,900	73,200	67,300	69,300
UV IV	77,700	81,200	81,800	77,500	72,100	71,700
UV V	67,100	79,500	74,300	71,400	74,600	60,900

* Average of five specimens.

TABLE A-24. SUMMARY OF ULTIMATE FLEXURAL STRENGTHS OF POLYESTER LAMINATES CONTAINING ULTRAVIOLET-ABSORBING AGENTS(19)

Panel	Weight Loss* for Indicated Exposure, per cent: 2 pyrons 100 hours 287°F max	2 pyrons 200 hours 292°F max	3 pyrons 100 hours 302°F max	3 pyrons 125 hours 305°F max	6 pyrons 6 hours 428°F max
UV I	0.63	0.95	1.38	1.91	8.70
UV II	0.35	0.43	0.57	0.88	7.62
UV III	0.31	0.38	0.57	0.89	7.49
UV IV	0.31	0.40	0.60	0.95	7.49
UV V	1.15	1.93	2.16	2.71	8.75

* Average of five specimens.

TABLE A-25. TEST ENVIRONMENT AND RESULTS OF STATIC TEST: POTTING COMPOUNDS(6)

Material	Radiation Exposure: Gamma [ergs/gm(C)]	Neutrons (n/cm²): Thermal	Neutrons: E>2.9 Mev	Neutrons: E>8.1 Mev	Sample Weight: Original, gm	Sample Weight: Change, gm	Ultimate Compressive Strength, psi	Temperature Average (°F)	Pressure Average (torr)
DC R-7521 (silicone)	0	0	0	0	-	-	23424 22940	77	760
		(Control specimens)					23182/429		
	9.03(9)	2.9(14)	1.4(15)	5.1(13)	8.5021 7.6400 7.7806	+0.0011 +0.0010 +0.0009	24103 20791 17539	117	2(-6)
		(Vacuum irradiation)					20811/3877		
Epon 828/z (epoxy)	0	0	0	0	-	-	19811 19621	77	760
		(Control specimens)					19716/168		
	1.0(10)	3.1(14)	1.6(15)	5.8(13)	9.8382 9.8654 9.8658	-0.0102 -0.0086 -0.0097	20833 20892 20849	116	2(-6
		(Vacuum irradiation)					20858/35		

TABLE A-26. TEST ENVIRONMENT AND RESULTS FOR LOW-FORCE DYNAMIC-TEST MATERIALS: POTTING COMPOUNDS(6)

Material and Test Equipment	Radiation Exposure: Gamma [ergs/gm(C)]	Neutrons (n/cm^2): Thermal	Neutrons: E>2.9 Mev	Neutrons: E>8.1 Mev	Sample Weight: Original, gm	Sample Weight: Change, gm	Compressive Strength, psi: 0.02 Inch Deflection	Compressive Strength, psi: At 25 Per Cent Deflection	Temperature Average (°F)	Pressure Average (torr)
RTV-60 (silicone)										
Instron Tester	0	0	0	0	-	-	22.5	218	77	760
		(Control specimens)					21	200		
							20	210		
							19	185		
							22	198		
							20.9/1.4	202.2/12.5(a)		
Low-Force Tester	0	0	0	0	-	-	41	-	77	760
		(Control specimens)								
Low-Force Tester	8.6(9)	1.5(14)	1.4(15)	5.4(13)	-	-	72.5	-	170	3(-7)
		(Vacuum irradiation)								
Instron Tester	8.6(9)	1.5(14)	1.4(15)	5.4(13)	11.8049	-0.0715	96	1508	167	3(-7)
		(Vacuum irradiation)			12.2921	-0.0789	109	1590		
							102/9.5	1549/71.8		

(a) Average value/standard deviation on an individual basis.

TABLE A-27. TEST ENVIRONMENT AND RESULTS OF STATIC TESTS: POTTING COMPOUNDS (COMPRESSION BUTTONS)(7)

Material Trade Name	Radiation Exposure: Gamma ergs/gm(C)	Neutron (n/cm²): Thermal	Neutron (n/cm²): E>2.9 Mev	Neutron (n/cm²): E>8.1 Mev	Time Until Test, days	Sample Weight: Original, gm	Sample Weight: Change	Compression Yield, psi	Crushing Load, lb	Compression Strength, psi	Strength At 25 percent Compression, psi	Temperature Avg., F	Press. Avg., torr
Scotchcast 212 Epoxy	0	0	0	0	-			8,505 10,441 10,415 9787/1144	2,740 2,220 2,950 2637/431	13,955 11,306 15,024 13,428/2196			
		(Control specimens)											
	6.8(8)	2.4(13)	1.2(14)	4.9(12)	9			9,091 - 9,091/X	2,450 3,250 2850/709	12,473 16,552 14,515/3612		32	-
		(Air irradiation)											
	1.36(9)	1.8(13)	2.5(14)	9.5(12)	9			9,473 9,829 10,033 9,778/331	2,500 2,435 2,350 2,428/89	12,732 12,401 11,968 12,387/451		82	-
		(Air irradiation)											
	3.9(10)	2.8(14)	6.1(15)	5.90(13)	16			- - 8,938 - 8,938/X	3,010 1,550 3,555 3,000 2,779/974	15,330 11,968 18,105 15,279 15,171/2981		100	-
		(Air irradiation)											
	4.7(8)	2.0(13)	[illegible]4(13)	2.4(12)	9			3,607 3,938 3,913 3,244 3,467 8,974/274	2,490 3,050 2,350 2,290 2,480 2,532/327	12,681 15,533 11,968 11,663 12,632 12,895/1664		90	4(-7)
		(Vacuum irradiation)											
	9.4(8)	2.8(13)	[illegible]5(14)	5.6(12)	9			9,422 9,677 9,575 9,473 9,537/124	2,070 2,750 2,760 2,175 2,439/335	10,542 14,006 14,057 11,077 12,421/1707		90	[illegible](-7)
		(Vacuum irradiation)											
	2.85(10)	3.88(14)	5 [illegible].15)	2.09(14)	22			17,851 17,545 17,690 17,698 17,698/149	3,120 3,250 3,180 3,350 3,348/350	17,851 17,545 17,698 19,557 18,163/977		200	6(-7)
		(Vacuum irradiation)											
Durock D-133	0	0	0	0	—						21,380 5,608* 20,852 24,116/3232		
		(Control specimens)											
	3.9(10)	2.8(14)	6.1(15)	2.6([illegible])	25						30,429 34,722 33,459 32,870/2035	[illegible]	--
		(air irradiation)											

TABLE A-27. (Continued)

Material Trade Name	Gamma [ergs/gm(C)]	Radiation Exposure, Neutron (n/cm²) Thermal	E>2.9 Mev	E>8.1 Mev	Time Until Test, days	Sample Weight, Original gm	Change gm	Compression Yield psi	Crushing Load, lb	Compression Strength psi	Strength At 25 percent Compression, psi	Temperature Avg., F	Press Avg., torr
	3.43(12)	4.07(14)	7.56(15)	2.70(14)	24	21.1643 21.0721 21.1106	-0.0004 -0.0015 -0.0011	—	—	—	6,313* 17,677 16,624 17,151/622	200	6(-7)
		(Vacuum irradiations)											
RTV-501 Silicone	0	0	0	0	-						134 126 139 133/8	-	-
		(Control specimens)											
	1.5(8)	3.3(12)	3.0(13)	1.1(12)	15						124 119 117 125 121/4	80	-
		(Air irradiation)											
	1.36(9)	1.8(13)	2.5(14)	9.5(12)	15						197.5 185 200 160.5 186/19	82	
		(Vacuum irradiation)											
	1.8(8)	8.4(12)	1.85(13)	7.6(11)	8	9.0581 8.9501 9.0108 8.9517	-0.0562 -0.0604 -0.0591 -0.0558				148 144 147 146 146/2	80	1.7(-7)
		(Vacuum irradiation)											
	4.7(8)	2.0(13)	6.4(13)	2.4(12)	9	9.0269 9.0227 9.0087 8.9402	-0.0521 -0.0525 -0.0557 -0.0556				164 159.5 154.5 157 159/5	90	4(-7)
		(Vacuum irradiation)											
	9.4(8)	2.8(13)	1.5(14)	5.6(12)	12	9.0601 8.9891 8.9849 8.9633	-0.0553 -0.0553 -0.0545 -0.0561				181.5 170 170 175 174/6	90	4(-7)
		(Vacuum irradiation)											
EC2273 Proprietary	0	0	0	0	-						457 457 430 419 441/18		
		(Control specimens)											

TABLE A-27. (C[illegible]ncluded)

Material Trade Name	Gamma [ergs/gm(C)]	Radiation Exposure: Neutron (n/cm²) Thermal	E>2.9 Mev	E>8.1 Mev	Time Until Test, days	Sample Weights Original, gm	Change, gm	Compression Yield, psi	Crushing Load, lb	Compression Strength, psi	Strength At 25 percent Compression, psi	Temperature Avg. F	Press Avg. torr
	1.5(8)	3.3(12) (Air irradiation)	3.0(13)	1.1(12)	15						452 463 442 450 [illegible]/10	80	—
	1.36(9)	1.8(13) (Air irradiation)	2.5(14)	9.5(12)	15						453 460 418 427 440/20	82	—
	6.0(9)	— (Vacuum irradiation)	1.26([illegible])	—	15						537 557 540 569 551/16	100	
	1.8(8)	8.4(12) (Vacuum irradiation)	1.85(13)	7.6(11)	8	10.3397 10.3520 10.3657 10.3376	+0.0154 +0.0172 +0.0[illegible] +0.0175				— 470 445 430 448/24	80	1.[illegible](-7)
	9.4(8)	2.8(13) (Vacuum irradiation)	1.5(14)	5.6(12)	12	10.3455 10.4134 10.2124 10.0138	+0.0084 +0.0099 +0.0082 +0.0081				[illegible] 62[illegible] 6[illegible] [illegible] 56[illegible]/89	90	[illegible]
	5.9(9)	1.13(14)	6.53(14)	—	12	10.4031 10.3362 10.3043 10.0884	-0.0023 -0.0042 -0.0146 -0.0221				535 548 521 521 531/13	160	[illegible]

* Values not included in calculating average and standard deviation.

Tested under atmospheric conditions.

TABLE A-28. TEST ENVIRONMENT AND RESULTS OF STATIC TEST: SEALS(6,7)

Material Trade Name	Radiation Exposure: Gamma ergs/gm(C)	Radiation Exposure: Neutrons (n/cm²) Thermal	Neutrons E>2.9 Mev	Neutrons E>8.1 Mev	Time Until Test, days	Sample Weight: Original, gm	Sample Weight: Change, gm	Tensile Strength[a] (psi) at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press. Avg., torr
Parker Compound 66-581 (Buna-N) O-rings	0	0 (control specimens)	0	0	—	—	—	—	—	280 270 280 281 278/6.31	1349 1322 1355 1300 1331/26.7	487 480 493 512 493/15.3	77	760
	8.06(9)	2.8(14) (vacuum irradiation)	1.2(15)	4.5(13)	—	1.5945 1.5988 1.6067	-0.0206 -0.0203 -0.0200	500 356 407 421/85.0	1155 1000 1150 1102/91.6	—	1818 1965 1690 1824/162	76 87 70 78/10.0	112[b]	2(-6)
	3.2(9)	(air irradiation)	4.7(14)		—	—	—	—	—	636/1.7/3	1530/3.8/3[c]	246/1.8/3	—	—
	1.1(10)	(air irradiation)	1.8(15)		—	—	—	—	—	1951/12/3	2077/9.1/4	104/13/4		
Parker Compound 66-581 (Buna-N) Tensile Specimens	0	0 (control specimens)	0	0	—	—	—	183 199 174 150 176.5/23.8	238 285 267 250 260/22.8	320 430 449 350 387.2/62.7	1440 1331 1423 1350 1386/52.9	412 408 425 415 415/8.2	77	760
	8.06(9)	2.8(14) (vacuum irradiation)	1.2(15)	4.5(13)		4.5873 4.9099 4.5546	-0.0645 -0.0613 -0.0590	820 860 782 821/40.1	—	—	1588 1740 1855 1728/158	55 62 70 62/8.9	112[b]	2(-6)
Buna N O-rings 66-581	0	0 (control specimens)	0	0	—	—	—	139 122 142 135 139 139 136/8	198 188 209 205 201 208 202/8	317 297 330 330 314 330 320/13	1339 1290 1355 1386 1381 — 1350/41	477 472 448 468 486 — 470/16	—	—
	1.5(8)	3.3(12) (air irradiation)	3.0(13)	1.1(12)	11	—	—	149 149 149 149 149 149/0	214 214 214 214 214 214/0	330 330 340 330 340 3[illegible]4/4	1368 1359 1355 1318 1314 1343/23	463 457 434 441 418 443/19	80	—
	1.36(9)	1.8(13) (air irradiation)	2.5(14)	9.5(12)	11	—	—	182 [illegible] [illegible] 165 158 167/10	264 264 251 251 248 256/7	429 445 429 429 429 432/7	1588 1505 1551 1437 1572 1531/65	409 365 402 349 398 385/26	82	—

TABLE A-[illegible] (Continued)

Material Trade Name	Radiation Exposure: Gamma (ergs/gm(C))	Neutron (n/cm²): Thermal	Neutron: E>2.9 Mev	Neutron: E>8.1 Mev	Time Until Test, days	Sample Weight: Original, gm	Sample Weight: Change, gm	Tensile Strength[a] (psi): at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press. Avg., torr
	7.5(7)	4.6(12)	5.2(12)	2.35(11)	10	1.1744	-0.0036	149	214	330	1370	472	80	1.7(-7)
		(vacuum irradiation)				1.1721	-0.0026	149	214	330	1386	453		
						1.1673	-0.0037	149	214	314	1355	485		
						1.1695	-0.0032	149	214	347	1341	428		
						1.1731	-0.0029	149	214	330	1355	451		
								149/0	214/0	330/14	1361/19	458/25		
	1.8(8)	8.4(12)	1.85(13)	7.6(11)	9	1.1741	-0.0019	158	228	347	1339	435	80	1.7(-7)
		(vacuum irradiation)				1.1759	-0.0018	149	224	350	1386	449		
						1.1783	-0.0021	149	218	350	1355	426		
						1.1771	-0.0016	145	221	350	1384	434		
						1.1751	-0.0024	142	214	340	1351	415		
								149/7	221/6	347/4	1363/20	432/15		
	9.1(8)	2.8(13)	1.6(14)	6.0(12)	7	1.1692	-0.0029	158	238	379	1496	432	90	4(-7)
		(vacuum irradiation)				1.2060	-0.0037	165	248	402	1560	450		
						1.1864	-0.0027	149	231	379	1470	427		
						1.1600	-0.0012	149	231	383	1396	372		
						1.1775	-0.0026	149	231	379	1532	438		
								154/7	236/7	384/10	1484/78	424/34		
Natural Rubber Compound RA33860 (O-ring)	0	0	0	0	—	—	—	—	—	—	1880	416	77	760
		(control specimens) September 1962						117	192	330	2030	456		
								108	180	313	2070	474		
								94	166	296	2270	477		
								101	176	316	2150	460		
								108	180	309	2095	468		
								108	173	302	2105	480		
								106/9.1	178/10.3	311/13.4	2081/144	462/23.7		
		(control specimens) February 1963			—	—	—	115	184	330	2206	441	77	—
								106	184	326	1936	423		
								106	181	326	2180	456		
								117	192	330	2241	468		
								124	206	337	1745	395		
								114/7.7	189/10.7	330/4.7	2072/213	437/31.4		
		(vacuum controls) February 1963			—	1.0029	-0.0101	121	195	340	1950	407	77	1(-6)
						0.9934	-0.0097	121	192	340	2177	444		
						0.9950	-0.0099	128	206	348	1997	426		
						0.9909	-0.0087	121	199	348	1906	425		
						0.9935	-0.0105	131	213	358	19[illegible]5	407		
								124/4.3	201/9.0	347/7.7	2005/113	422/15.9		
	9.03(9)	2.9(14)	1.4(15)	5.[illegible](13)	—	0.9971	-0.0001	2[illegible]	497	980	1100	120	112	2(-6)
		(vacuum irradiation)				0.9980	+0.0007	[illegible]	515	1010	1073	114		
						0.9932	+0.0006	270	515	1050	1073	109		
								277/8.[illegible]	509/10.6	1013/41.3	1082/43.1	114/6.5		

TABLE A-28. (Continued)

Material Trade Name	Gamma [ergs/gm(C)]	Radiation Exposure: Neutron (n/cm²) Thermal	E>2.9 Mev	E>0.1 Mev	Time Until Test, days	Sample Weights: Original, gm	Change, gm	Tensile Strength(a) (psi): at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Ultimate Elongation, percent	Temperature Avg, °F	Press Avg, torr
Natural Rubber O-rings RA33860	0	0	0	0	—	—	—	91	152	258	1965	477	—	—
		(control specimens)						91	139	236	1803	478		
								91	139	249	1963	498		
								85	130	218	1645	470		
								85	133	230	1741	471		
								91	136	230	173[illegible]	472		
								91	136	236	172[illegible]	468		
								91	139	245	17[illegible]	478		
								91	145	249	1832	458		
								90/2	139/7	239/13	1796/108	474/13		
	6.8(8)	2.4(13)	1.2(14)	4.9(12)	11	—	—	100	167	261	1760	445	82	—
		(air irradiation)						91	152	258	1721	431		
								91	152	258	1893	455		
								97	152	258	1910	478		
								97	152	258	1565	402		
								95/4	155/6	259/1	1770/148	442/33		
	6.0(9)		1.26(15)		16	—	—	136	236	467	1239	249	82	—
		(air irradiation)						136	242	449	1480	313		
								136	236	455	1521	316		
								142	236	449	1560	324		
								145	242	470	1767	368		
								139/4	238/3	458/9	1513/227	314/51		
	4.45(8)	1.95(13)	5.45(13)	2.1(12)	7	1.0282	-0.0112	97	164	273	1605	417	90	[illegible]
		(vacuum irradiation)				1.0270	-0.0108	94	157	266	1765	440		
						1.0289	-0.0107	91	164	285	1780	422		
						1.0194	-0.0107	100	167	288	1780	438		
						1.0233	-0.0102	—	—	—	—	—		
								96/4	162/5	278/11	1733/85	429/11		
	9.1(8)	2.3(13)	[illegible]6(14)	6.0(12)	7	1.0212	-0.0115	112	176	303	1797	428	90	4(-7)
		(vacuum irradiation)				1.0198	-0.0115	112	167	288	1865	4[illegible]4		
						1.0306	-0.0102	106	167	279	1815	442		
						1.0212	-0.0126	112	176	309	1965	449		
						1.0264	-0.0120	112	197	288	1880	451		
								111/3	177/13	293/13	1864/72	443/10		
	4.1(9)	6.4(13)	3.7(14)	1.6(13)	8	1.0267	-0.0177	151	242	445	1665	307	160	3(-7)
		(vacuum irradiation)				1.02[illegible]1	-0.0187	136	230	424	1365	263		
						1.0279	-0.0200	139	239	421	1939	356		
						1.0296	-0.0204	[illegible]	227	409	1222	249		
						1.0337	-0.0191	[illegible]	206	394	1605	316		
								13[illegible]	229/15	419/22	1559/308	29[illegible]/46		

TABLE A 8. (Continued)

Material Trade Name	Radiation Exposure: Gamma, ergs/gm(C)	Neutron (n/cm²): Thermal	Neutron (n/cm²): E>2.9 Mev	Neutron (n/cm²): E>8.1 Mev	Time Until Test, days	Sample W[illegible]: Origin[illegible]	Sample W[illegible]: [illegible]ge.	Tensile Strength[a] (psi): at 25% Elongation	Tensile Strength[a] (psi): at 50% Elongation	Tensile Strength[a] (psi): at 100% Elongation	Tensile Strength[a] (psi): Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press Avg., torr
Neoprene O-rings PRP2277	0	0 (control specimens)	0	0	—	—	—	184 174 174 167 154 151 167/13	308 291 278 274 268 290 285/16	585 561 521 521 508 485 530/39	2875 2648 2521 2601 2540 [illegible] 2651/140	294 288 285 [illegible] 292 322 294/15	—	—
	1.5(8)	3.3(12) (air irradiation)	3.0(13)	[illegible].1(12)	11	—	—	167 167 181 184 177 175/7	264 278 284 288 278 278/10	485 532 535 552 502 521/29	[illegible] [illegible] [illegible] 2275 2962 2580/376	355 243 298 253 371 304/51	80	—
	1.36(9)	1.[illegible](13) (air irradiation)	2.5(14)	9.5(12)	11	—	—	151 201 201 211 201 193/26	284 335 342 352 335 330/29	552 669 669 669 669 646/50	2641 2523 2329 2820 1840 2431/421	301 243 231 276 201 250/43	82	—
	1.8(8)	8.4(12) (vacuum irradiation)	1.85(13)	7.[illegible](11)	9	1.3162 1.3351 1.3273 1.3210 1.3224	-0.0049 -0.0037 [illegible].0050 -0.0053 -0.0045	184 167 17[illegible] 167 167 172/7	291 274 294 301 284 289/12	562 519 569 585 519 551/28	2815 2960 2760 2694 2535 2753/183	304 352 310 292 310 314/26	8[illegible]	1.[illegible](-7)
	4.45(8)	1.95(13) (vacuum irradiation)	5.45(13)	2.1(12)	7	1.3270 1.3211 1.3351 1.3254 1.3290	-0.0054 -0.0052 -0.0056 -0.0048 -0.0046	201 167 1[illegible] 1[illegible] 191 187/15	318 291 311 301 318 308/12	619 575 569 603 585 590/21	2341 2810 2519 2571 2328 2514/207	— 298 279 264 256 274/18	90	4(-7)
	9.1(8)	2.2(13) (vacuum irradiation)	1.6(14)	6.0(12)	7	1.3285 1.3302 1.3328 1.3261 1.3273	-0.0050 -0.0050 -0.0054 -0.0058 -0.0053	184 184 194 201 184 189/7	318 308 335 335 318 323/12	619 569 652 635 603 616/36	2678 2943 2571 2694 2392 2656/194	276 332 253 267 252 276/34	90	4(-7)
Viton B O-rings PRP19007	0	0 (control specimens)	0	0	—	—	—	[illegible] [illegible] — 18[illegible] 198 196/11	287 315 — 280 297 295/17	553 605 — 560 587 576/25	2010 1999 1485 1835 1940 1854/226	280 261 216 259 264 256/28	—	—

TABLE A-20. (Continued)

Material Trade Name	Radiation Exposure: Gamma [ergs/gm(C)]	Neutron (n/cm²): Thermal	Neutron (n/cm²): >2.9 Mev	Neutron (n/cm²): >0.1 Mev	Time Until Test, days	Sample Weight: Original, gm	Sample Weight: Change, gm	Tensile Strength[a] (psi): at 25% Elongation	Tensile Strength[a] (psi): at 50% Elongation	Tensile Strength[a] (psi): at 100% Elongation	Tensile Strength[a] (psi): Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press. Avg., torr
	1(9) (estimated) (air irradiation)				13	—	—	280 280 266 273 283 276/7	524 559 524 552 594 551/30	1294 1311 1303 1336 1339 1318/19	1825 1888 1538 1860 1566 1735/150	137 140 115 126 122 128/11	105	—
	5(9) (estimated) (air irradiation)				13	—	—	1224 1182 1189 1189 1196/20	—	—	2028 [illegible] [illegible] 2080 1969/124	44 45 44 47 45/1	125	—
	3.1(8)	6.98(12) (vacuum irradiation)	3.92(13)	1.56(12)	8	—	—	210 210 213 206 217 211/5	350 367 374 350 385 365/15	798 798 794 770 840 800/30	2010 2058 2030 2030 2181 2063/76	211 215 204 214 215 212/[illegible]	85	2.5(-7)
	5.08(8)	8.31(12) (vacuum irradiation)	5.98(13)	2.77(12)	8	—	—	224 227 227 227 240 226/3	395 402 385 420 402 402/15	899 927 927 927 927 921/12	1672 2162 2140 2145 1865 1997/211	[illegible] [illegible] [illegible] [illegible] 177 187/1[illegible]	87	2.5(-7)
PRP737-70 FLX O-rings	0	0 (control specimens)	0	0	—	—	—	18[illegible] 230 196 230 196 186 204/17	339 339 339 359 346 346 345/8	848 846 830 864 864 820 846/17	2161 2000 1932 1865 1932 1870 1960/117	231 212 207 201 203 202 209/12	—	—
	1(9) (estimated) (air irradiation)				13			278 271 247 258 241 259/16	522 475 481 505 492 459/20	1288 1207 1271 1451 1261 1296/105	2230 2166 2302 2197 2176 2214/58	181 181 187 180 184 182/3	105	—
	5(9) (estimated) (air irradiation)				13	—	—	475 492 458 [illegible] [illegible] [illegible]	1125 1146 1078 1017 977 1073/64	— 2658 — — — —	2593 2780 2427 2447 2508 2551/152	98 102 93 93 95 96/4	125	—

TABLE A ?3. (Concluded)

Material Trade Name	Radiation Exposure: Gamma [ergs/gm(C)]	Neutron (n/cm^2): Thermal	Neutron (n/cm^2): E>2.9 Mev	Neutron (n/cm^2): E>8.1 Mev	Time Until Test, days	Sample Weight: Original gm	Sample Weight: Change, gm	Tensile Strength[a] (psi): at 25% Elongation	Tensile Strength[a] (psi): at 50% Elongation	Tensile Strength[a] (psi): at 100% Elongation	Tensile Strength[a] (psi): Ultimate	Ultimate Elongation, percent	Temperature Avg., °F	Press. Avg., torr
	3.1(8)	6.98(12) (vacuum irradiation)	3.92(13)	1.56(12)	8	—	—	196	373	909	1750	176	85	2.5(-7)
								186	380	915	1949	196		
								186	380	881	1220	133		
								186	356	915	1994	204		
								196	369	949	1762	177		
								190/4	376/14	914/29	1735/333	177/31		
	5.08(8)	8.31(12) (vacuum irradiation)	6.98(13)	2.77(12)	8	—	—	220	424	1032	1840	—	87	2.5(-7)
								230	389	983	[illegible]	189		
								186	389	949	[illegible]	188		
								196	407	1016	17[illegible]9	161		
								230	389	966	1830	179		
								212/19	400/15	989/36	1877/91	179/14		

(a) Values given as: average value/standard deviation on an individual basis.

(b) Estimated value based on similar temperatures of natural rubber.

(c) Average value/standard deviation on an individual basis/number of specimens

Tested under atmospheric conditions.

TABLE A-29. LOW-FORCE DY''AMIC TEST RESULTS(6)

Material and Test Equipment	Radiation Exposure: Gamma ergs/gm(C)	Neutrons (n/cm²): Thermal	Neutrons (n/cm²): E>2.9 Mev	Neutrons (n/cm²): E>8.1 Mev	Machine Crosshead Speed (in./min.)	Tensile Strength (psi): at 25% Elongation	Tensile Strength (psi): at 50% Elongation	Tensile Strength (psi): at 100% Elongation	Tensile Strength (psi): Ultimate	Ultimate Elongation, per cent	Temperature Average, F	Pressure Average, torr
Viton B (PRP 1900) Instron Tester	0	0 (control specimens) September 1962	0	0	0.5	— 330 288 330 322 318/20	— 495 429 495 486 476/32	— 925 834 890 883 883/45	1302 1305 1334 1365 1312 1334/27	103 146 159 157 152 157/4.9(a)	77	760
Low-Force Tester	9.0(9)	1.4(14) (vacuum irradiation) September 1962	1.7(15)	6.75(13)	0.5	—	—	—	1451 1398 1437 1429/27.5	34 31.5 34 33.2/1.44	167	3(-7)
Instron Tester	9.0(9)	1.4(14) (vacuum irradiation) September 1962	1.7(15)	6.75(15)	0.5	—	—	—	1180 918 1049/144	19.8 17.1 18.5/2.4	167	3(-7)
Instron Tester	0	0 (control specimens) January 1962	0	0	20.0	—	—	—	1984/4.5/3	254/3.1/3	—	—
Instron Tester	1.2(9)	(air irradiation) January 1962	2.3(14)		20.0	—	—	—	2047/8.9/3	141/3.8/3	—	—
Instron Tester	0	0 (control specimens) October 1962	0	0	20.0	—	—	—	1710 1405 1650 1585 1607/96	183 [illegible] 165 165 166/13	—	—

(a) Average value/standard deviation on an individual basis/number of specimens.

TABLE A-30. LOW-FORCE DYNAMIC TEST RESULTS(6)

Material Trade Name	Radiation Exposure: Gamma ergs/gm(C)	Radiation Exposure: Neutron (n/cm²) Thermal	Neutron (n/cm²) E>2.9 Mev	Neutron (n/cm²) E>8.1 Mev	Tensile Strength(a) (psi) at 25% Elongation	Tensile Strength(a) (psi) at 50% Elongation	Tensile Strength(a) (psi) at 100% Elongation	Tensile Strength(a) (psi) Ultimate(b)	Ultimate Elongation(b), per cent	Temperature Average, F	Pressure Average, torr
					Run I, April 24, 1963						
Buna N O-rings	1.68(8)	1.7(12) (vacuum irradiation)	1.9(13)	—	93 94 93.5/1	169 175 122/5	285 277 281/7			85	2.3(-7)
Neoprene O-rings	1.68(8)	1.7(12) (vacuum irradiation)	1.9(13)	—	110 140 125/13	210 200 205/9	455 496 476/36			85	2.3(-7)
					Run II, June 4, 1963						
Buna N O-rings	5.08(8)	8.31(12) (vacuum irradiation)	6.98(13)	2.77(12)	110 125 134 123/14	200 205 210 205/6	347 356 377 360/18			87	2.5(-7)
Neoprene O-rings	5.08(8)	8.31(12) (vacuum irradiation)	6.98(13)	2.77(12)	195 173 184/20	333 300 317/29	560 500 530/33			87	2.5(-7)

(a) Values given as: average value/standard deviation on an individual basis.

(b) Not reached in test.

TABLE A-31. EFFECT OF NUCLEAR RADIATION ON SEALS, STATIC TESTS(6)

Category	Trade Name	Gamma Dose [ergs/gm(C)]	Vacuum (torr)	Specimen Configuration	Measured Property	Change in Measured Property, per cent
Seals	Natural Rubber	0 Vacuum Controls	1×10^{-6}	O-Rings	Ultimate tensile strength	0
					Ultimate elongation	0
					Weight change	+1
		9.0×10^{9}	2×10^{-6}	O-Rings	Ultimate tensile strength	-48
					Ultimate elongation	-75
					Weight change	0
	Viton B PRP 19007	9.0×10^{9}	3×10^{-7}	O-Rings	Ultimate tensile strength	-21
					Ultimate elongation	-88
	Parker Compound 66-581 (Buna N)	8.1×10^{9}	2×10^{-6}	O-Rings	Ultimate shear strength	+37
					Ultimate elongation	-85
					Weight change	-1.27
		8.1×10^{9}	2×10^{-6}	Tensile (ASTM-D-412-51T, Die C)	Ultimate tensile strength	+25
					Ultimate elongation	-85
					Weight change	-1.32
		3.2×10^{9}	Air Irrad.	O-Rings	Ultimate tensile strength	+15
					Ultimate elongation	-50
		1.1×10^{10}	Air Irrad.	O-Rings	Ultimate tensile strength	+56
					Ultimate elongation	-79.5
	Viton B PRP 19007	9.0×10^{9}	3×10^{-7}	O-Rings	Ultimate tensile strength	+7
					Ultimate elongation	-79

TABLE A-32. EFFECT OF VACUUM AND GAMMA RADIATION ON SEALS(35)

Specimen No.	Code	Weight Change, percent	Change in Shore Durometer Hardness
1A	Alleghany Plastic	-.01	-
B	Teflon X	0	-
2A	TDXE 121 No. 72	1.08	-2
B	Acrylonitrile	1.06	-1
3A	50% Teflon	-.01	-3
B	Loaded XIT351	-.04	-3
4A	TDXE-35 No. 74	1.16	-10
B	Acrylonitrile	1.10	-7
5A	Rubber	-.85	-9
B	366 YV	-.85	-4
6A	En-Jay Butyl	-.09	+2
B	XI 351	-.09	+2
7A	Rubber	0	-14
B	524A	0	-7
8A	Linear	0	-1
B	Copolymer XP-9-13	0	-1
9A	Parker	1.00	-10
B	B-496-7	1.00	-
10A	Rubber	1.00	+2
B	524A	1.00	+4
11A	Neoprene	-.53	0
B	No. 74 Compound	1.007	0
12A	Neoprene	1.009	0
B	No. 72 Compound	1.007	0
13A	Rubber	-.86	+1
B	366 YV	-.79	+2

TABLE A-33. FLUOROBESTOS TEST DATA[a][8]

I. Compression Tests (Federal Test Method 601-3331)

Specimen No.	Compressibility, percent	Recovery, percent
Control Test		
1	800.0	94.6
2	590.0	91.5
3	325.0	95.4
4	1,150.0	91.3
Average	716.2	93.2
Irradiated Specimens [10^9 erg/g(C)]		
1	331.8	95.9
2	657.1	93.5
3	500.0	95.0
4	940.0	93.6
Average	607.2	94.5

II Tensile Tests (Strain Rate = 0.1 in./min)

Specimen No.	Elastic Limit, psi	Elongation in 1 in., percent	Hardness, Shore B	0.2% Offset Yield Strength, psi	Ultimate Stress, psi
Control Test					
1	2,156	2.0	93.0	1,927	2,226
2	1,847	8.0	92.0	1,667	1,964
3	2,053	2.0	92.0	1,681	2,257
4	1,982	6.0	89.0	1,429	2,3[illegible]0
Average	2,009	4.5	91.5	1,676	2,206
Irradiated Specimens [10^9 erg/g(C)]					
1	495	0	86.0	542	554
2	957	2.0	85.0	1,081	1,106
3	1,005	4.0	86.0	1,130	1,176
4	1,058	3.0	86.0	1,128	1,222
Average[b]	1,007	3.0	85.7	1,113	1,168

(a) All specimens 0.07-inch thick (nominal).

(b) Data from Specimen No. 1 not included in average. Specimen defective.

TABLE A-34. TESTS WITH ELASTOMER SEALS(8)

Seal Type	Sample No.	Test Duration	Static Leakage (std cc He/sec)	Dynamic Leakage (std cc He/sec)
Reciprocating Seals				
Neoprene	1	Start	0.80	0.20
		30 min	2.40	1.00
	2	Start	0.54	0.24
		30 min	0.95	0.08
	3	Start	0.22	0.045
		30 min	0.0095	0.014
Silicone Rubber	1	Start	0.19	0.38
		30 min	0.26	0.33
	2	Start	0.87	1.50
		10 min (test stopped, leakage rate greater than 10 std cc/sec)		
	3	Start	2.50	3.40
		30 min	4.90	4.30
Viton A	1	Start	1.40	0.60
		40 min	0.02	0.20
	2	Start	0.35	0.65
		30 min	0.13	0.17
	3	Start	0.0001	0.20
		35 min	0.50	0.10
Kel-F	1	Start	1.00	0.12
		20 min (seal failure)	-	-
	2	Start	0.31	0.07
		10 min (seal failure)	-	-
	3	Start	0.10	0.14
		10 min (seal failure)	-	-
Buna N	1	Start	0.36	0.03
		30 min	0.10	0.032

TABLE A-34. (Continued)

Seal Type	Sample No.	Test Duration	Static Leakage (std cc He/sec)	Dynamic Leakage (std cc He/sec)
Reciprocating Seals				
Buna N	2	Start	0.55	0.040
		30 min	0.10	0.15
	3	Start	0.32	0.24
		30 min	0.10	0.18
Butyl	1	Start	0.80	0.28
		30 min	0.02	0.06
	2	Start	0.22	0.20
		30 min	0.038	0.038
	3	Start	0.004	0.03
		30 min	0.47	0.50
Polyethylene	1	Start	0.0001	0.005
		30 min	0.0001	0.012
	2	Start	0.0001	0.004
		30 min	0.002	0.01
	3	Start	0.2	0.10
		30 min	0.0001	0.005
Vinylite	1	Start	0.0090	0.20
		30 min	0.0040	0.60
	2	Start	0.0010	0.01
		30 min	0.0010	0.02
	3	Start	0.0010	0.03
		30 min	0.0010	0.01
Rotating Seals				
Kel-F	1	Start	0.28	0.50
		30 min	0.30	1.00
	2	Start	0.26	0.48
		30 min (seal destroyed by wear and abrasion)		0.16

TABLE A-34. (Concluded)

Seal Type	Sample No.	Time Duration	Static Leakage (std cc He/sec)	Dynamic Leakage (std cc He/sec)
Rotating Seals				
Kel-F	3	Start	0.34	0.38
		30 min (seal destroyed by wear and abrasion)		-
Silicone Rubber	1	Start	0.044	0.06
		30 min	0.35	0.80
	2	Start	0.15	0.26
		30 min	0.25	0.54
	3	Start	1.00	1.00
		30 min	0.28	0 [illegible]
Viton-A	1	Start	0.14	0.[illegible]3
		30 min	0.01	0.02
	2	Start	0.032	0.10
		30 min	0.016	0.019
	3	Start	0.10	0.22
		30 min	0.008	0.02
Kel-F Elastomer	1	Start	0.28	0.50
		30 min	0.30	1.0
	2	Start	0.34	0.38
		30 min	(a)	(a)
	3	Start	0.26	0.46
		30 min	(a)	(a)
Teflon	1 & 2	Start	0.1	(a)
		30 min	(a)	(a)

(a) Leakage excessive.

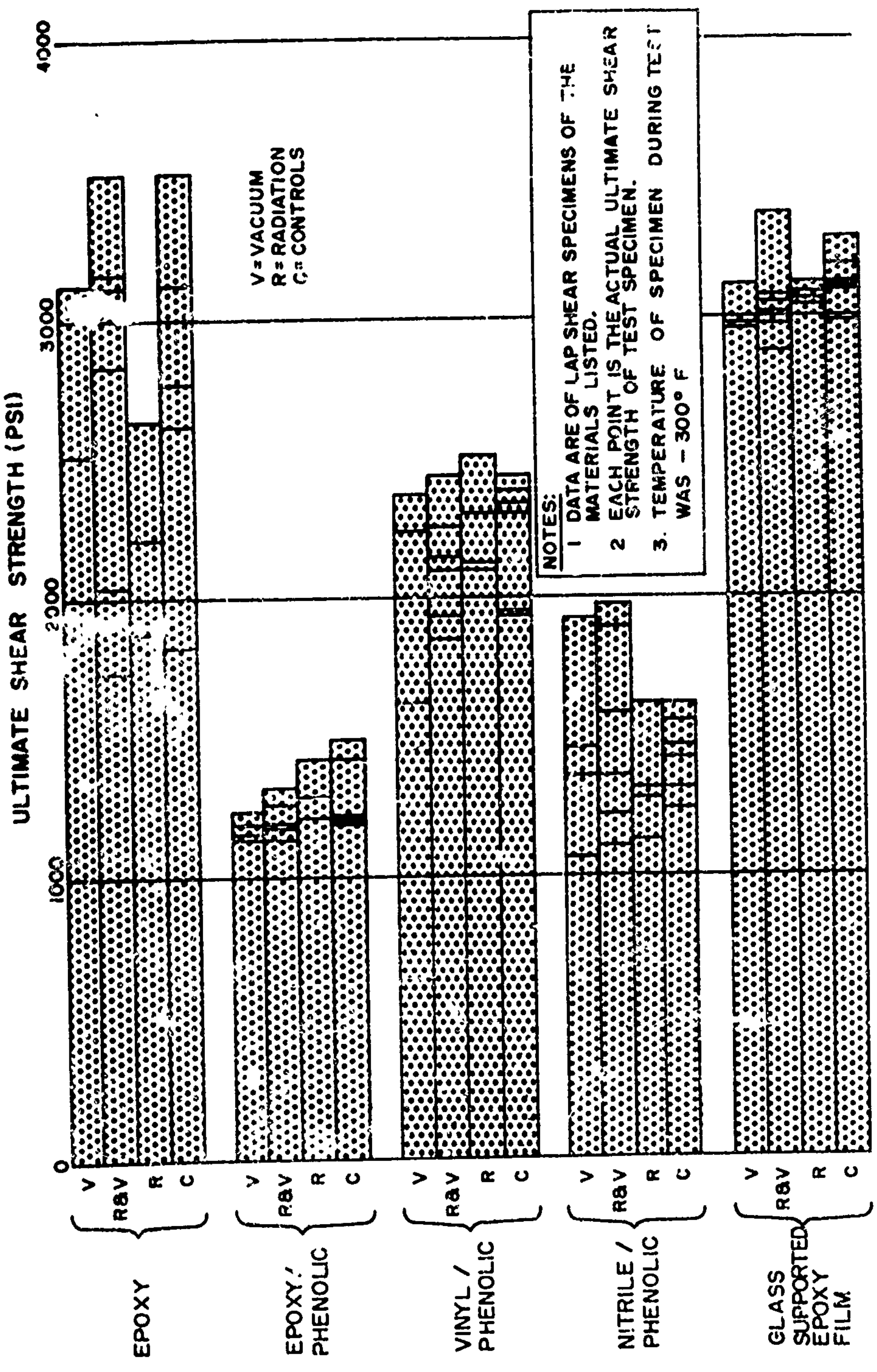


FIGURE A-1. COMBINED PARAMETER MATERIALS TESTS(8)

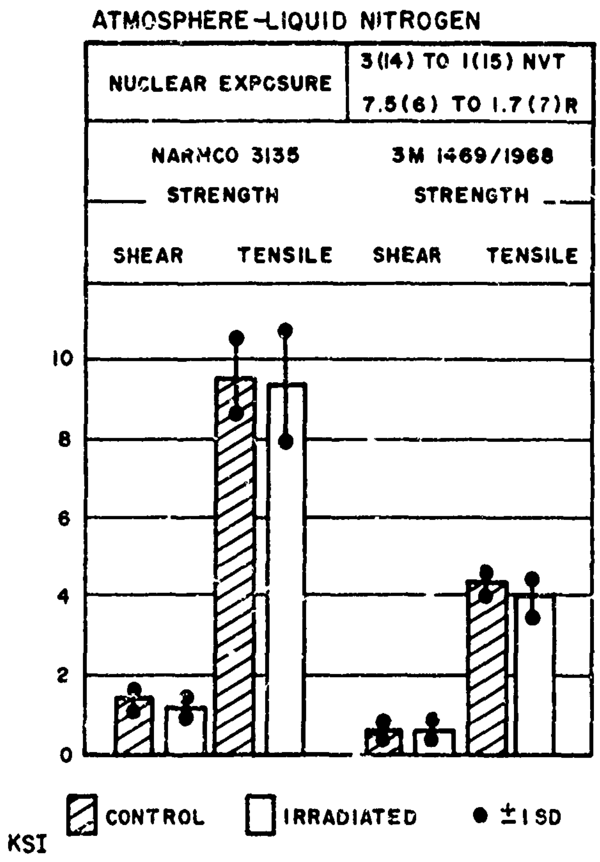


FIGURE A-2. RADIATION EFFECTS ON NARMCO 3135 AND 3M 1469/1968 ADHESIVES(13)

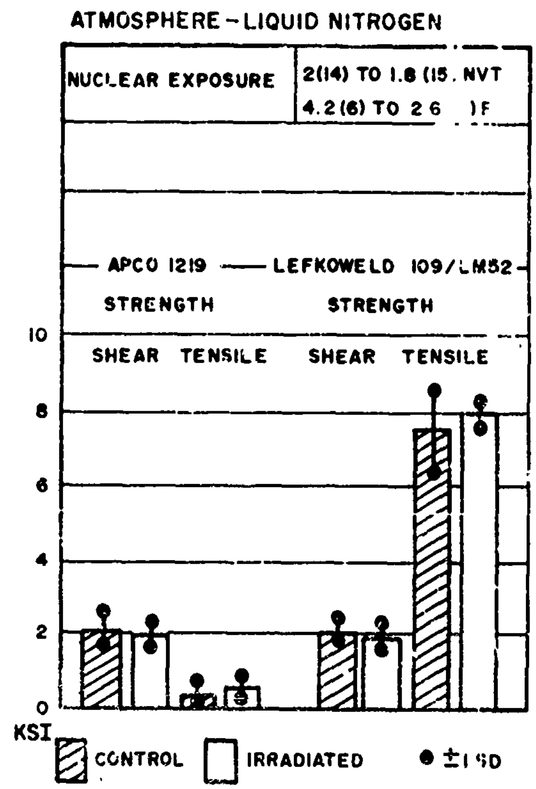


FIGURE A-3. RADIATION EFFECTS ON APCO 1219 AND LEFKOWELD 109/LM52 ADHESIVES(13)

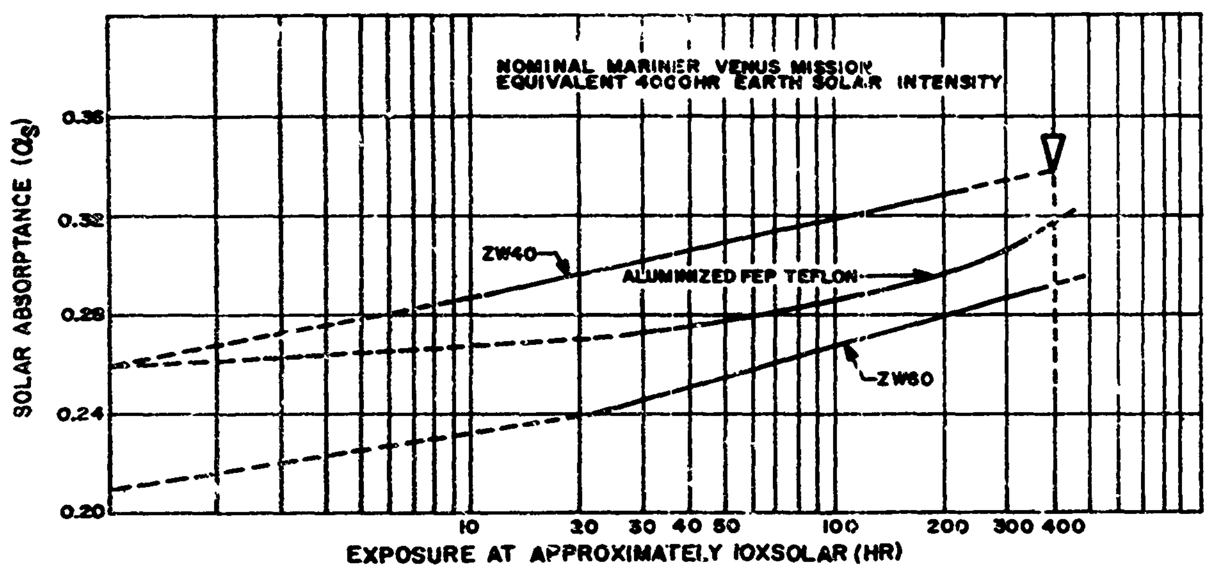


FIGURE A-4. ULTRAVIOLET DEGRADATION IN VACUUM, SPACECRAFT "WHITE" SURFACES(18)

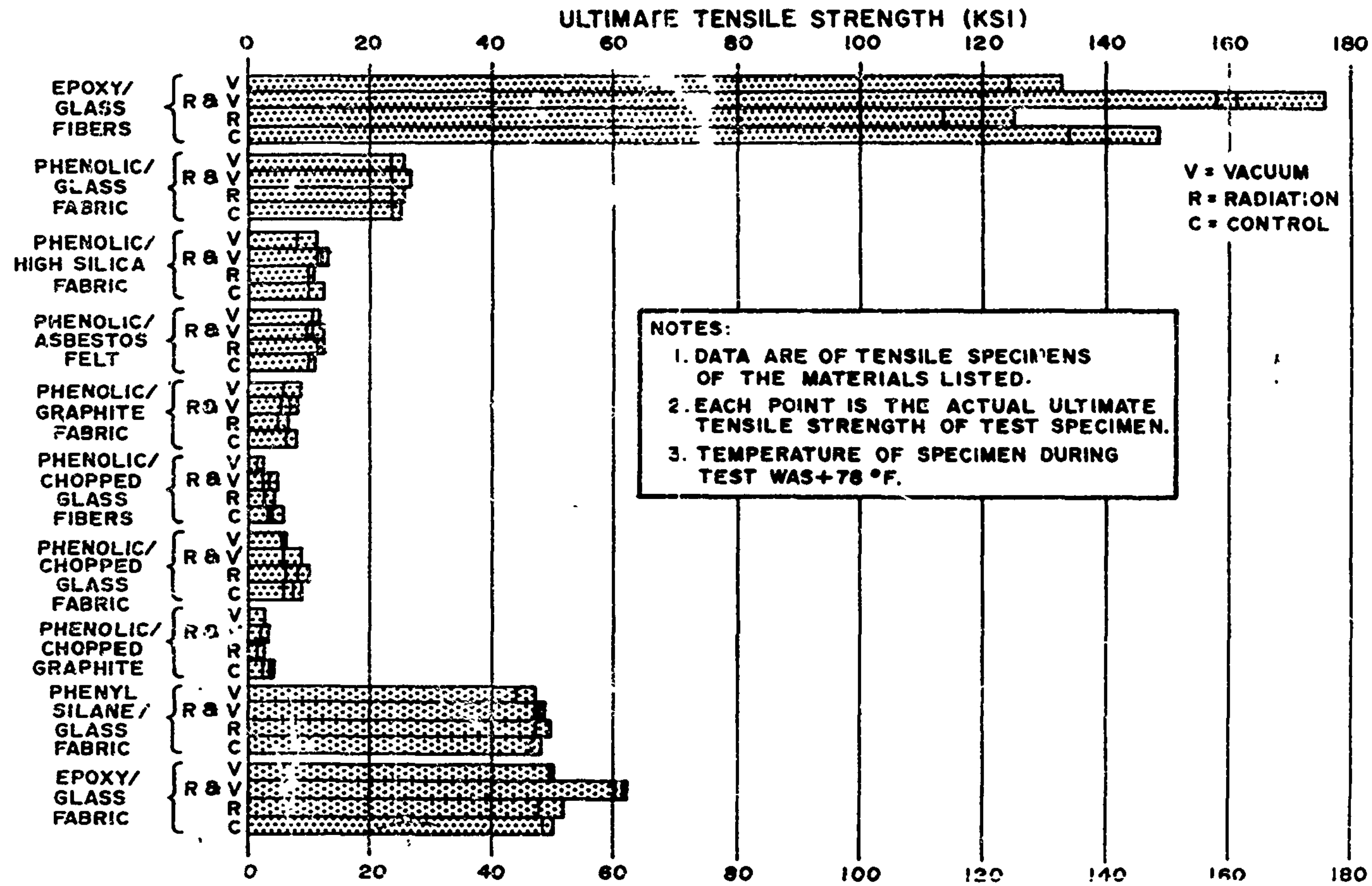


FIGURE A-5. COMBINED PARAMETER MATERIALS TEST(8)

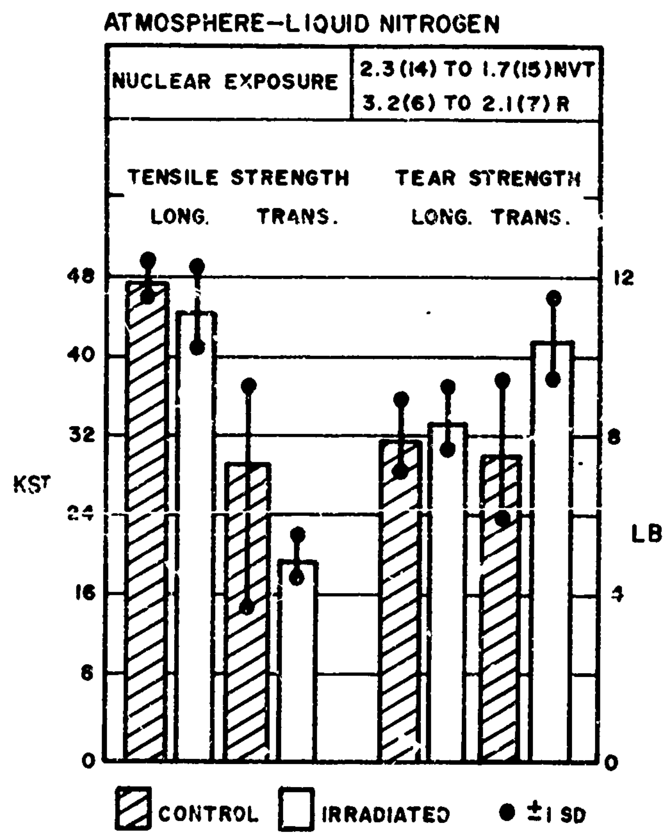


FIGURE A-6. RADIATION EFFECTS ON SINEWAVE LAMINATE(13)

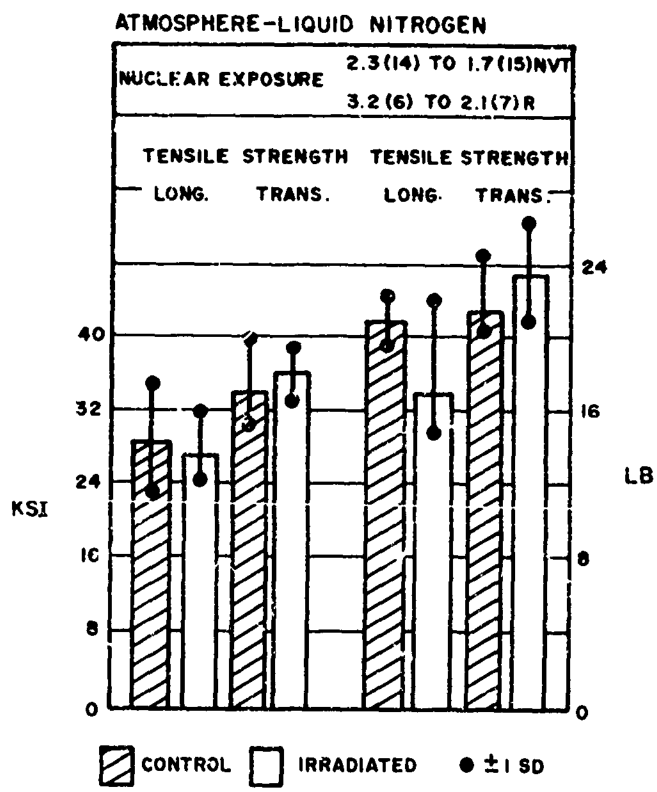


FIGURE A-7. RADIATION EFFECTS ON HEXCEL LAMINATE(13)

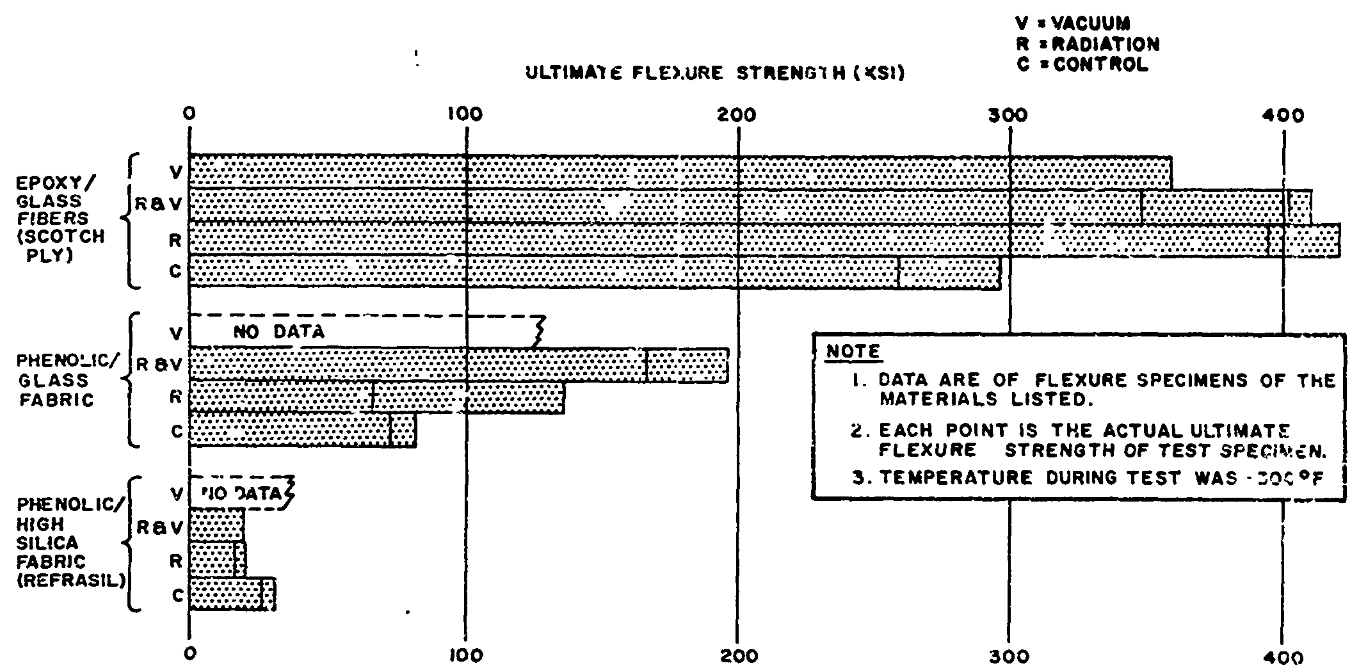


FIGURE A-8. COMBINED PARAMETER MATERIALS TESTS(8)

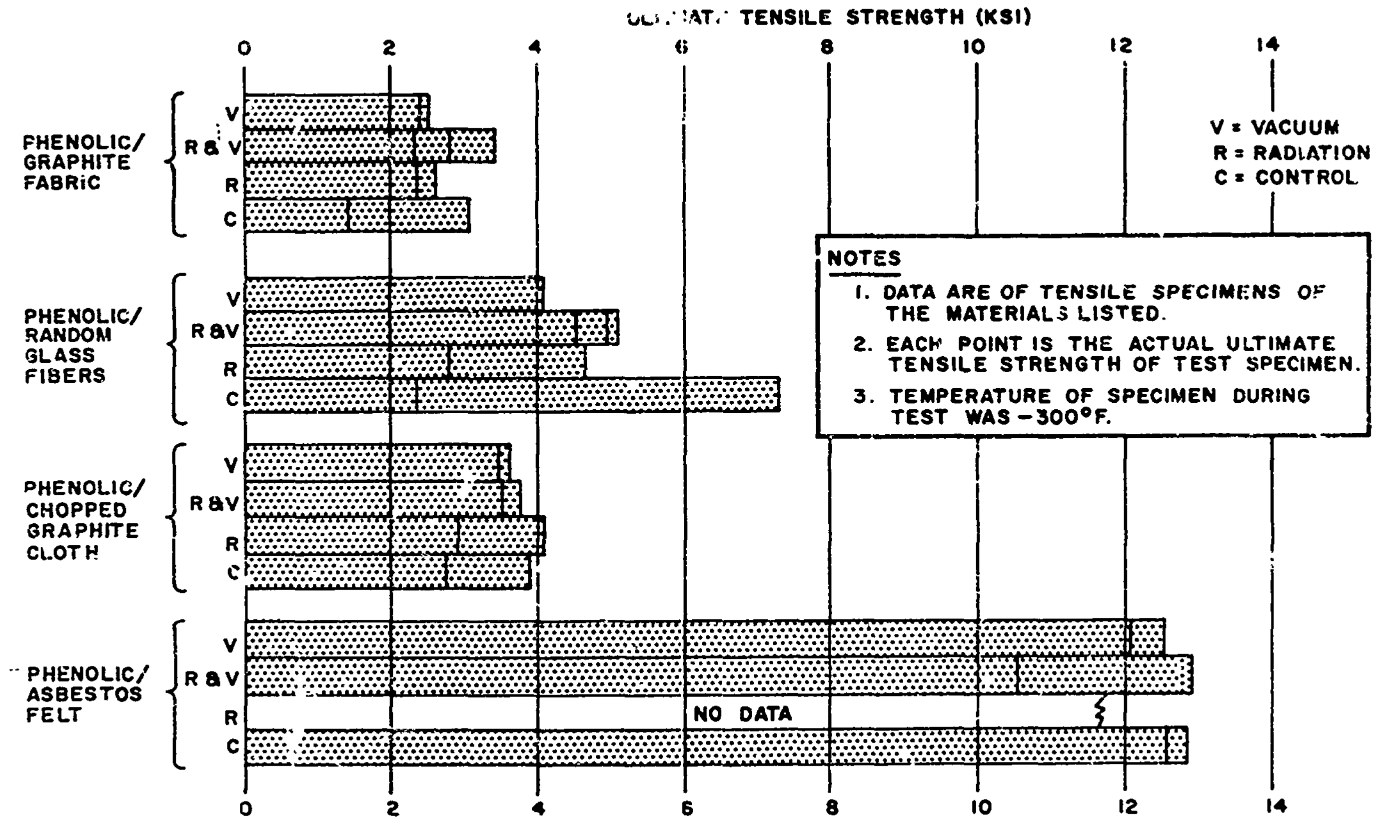


FIGURE A-?. COMBINED PARAMETER MATERIALS TESTS(8)

NOTES:

1. THE MATERIAL TESTED WAS THE LISTED RESINS IN A GLASS FABRIC LAMINATE SYSTEM.
2. EACH POINT IS ACTUAL ULTIMATE STRENGTH OF TEST SPECIMEN.
3. TEMPERATURE OF SPECIMEN DURING TEST WAS 300 °F

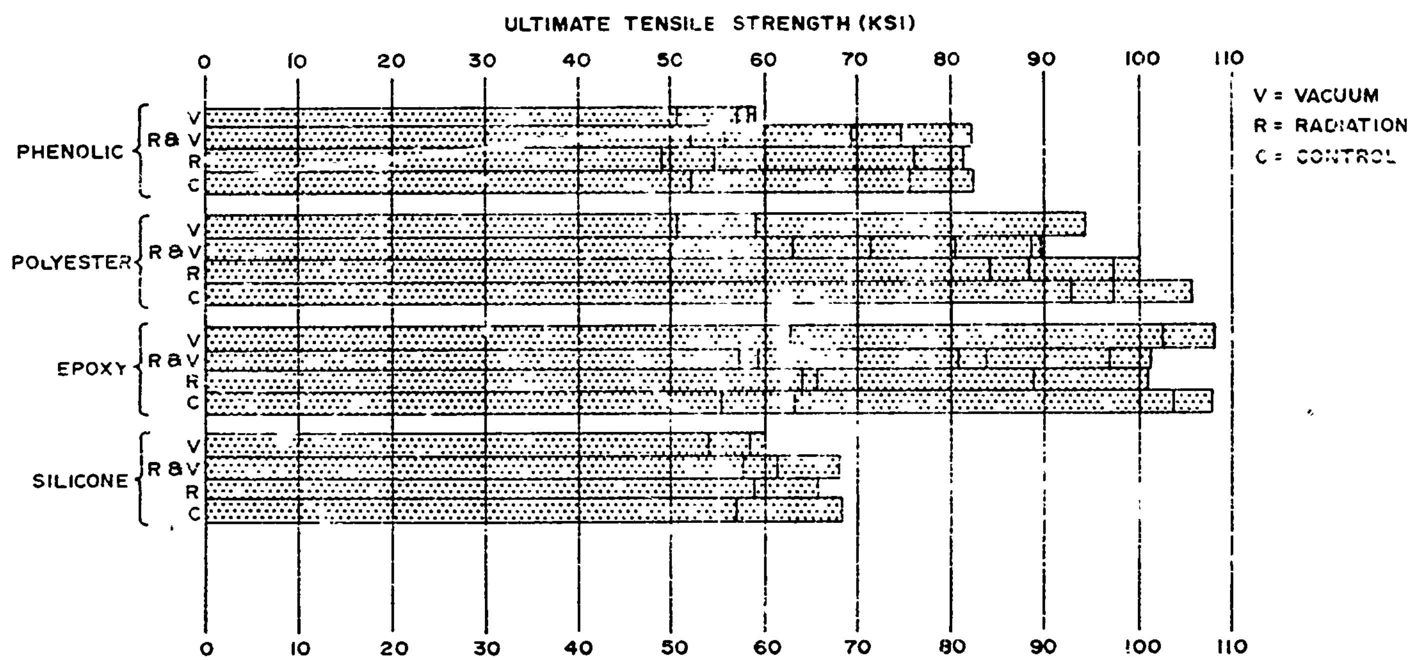
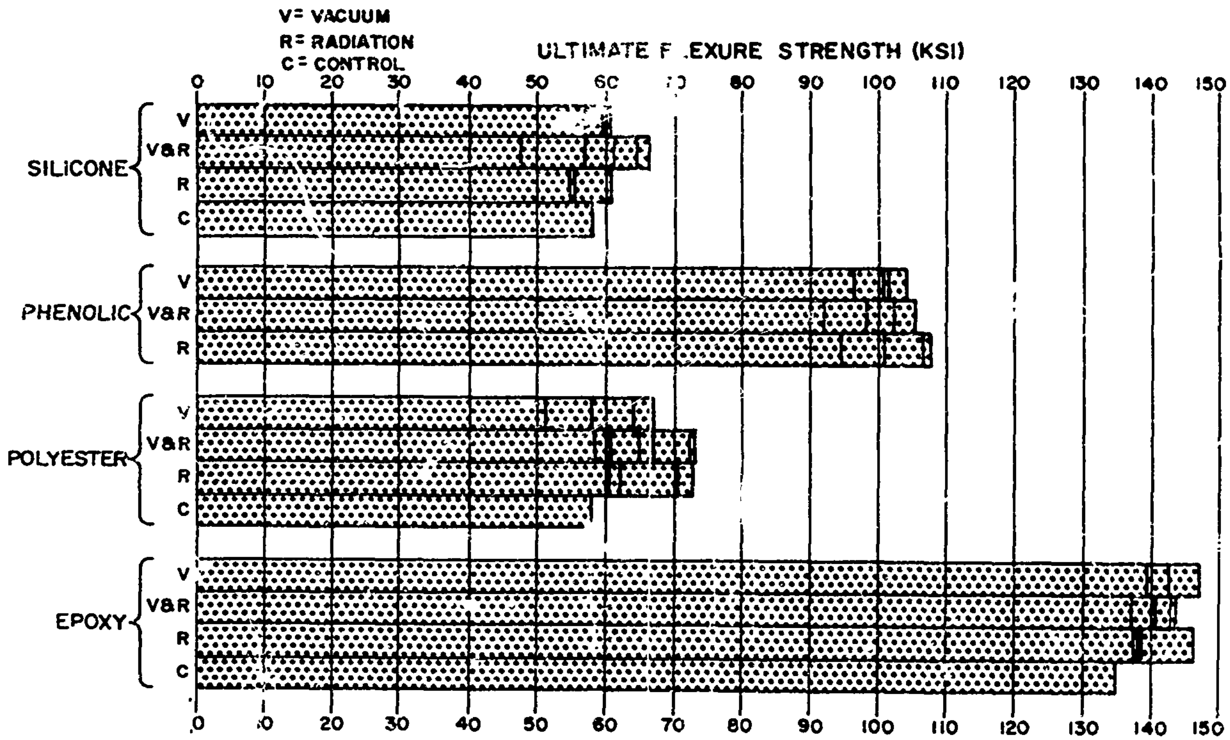


FIGURE A-1?. COMBINED PARAMETERS MATERIALS TESTS(8)



NOTES:

1. DATA ARE OF FLEXURE SPECIMENS OF THE MATERIALS LISTED.
2. EACH POINT IS THE ACTUAL ULTIMATE FLEXURE STRENGTH OF TEST SPECIMEN.
3. TEMPERATURE DURING TEST WAS -300° F.

FIGURE A-11. COMBINED PARAMETER MATERIALS TESTS(8)

APPENDIX B

ELASTOMERS

Table B-1. COMPOUND FORMULATIONS[45]

Compounding Ingredient	Parts by Weight										
	S119	S119B	N128	N128E	M72	M72E	Z72	Z74F	Z84	Z69 FCT	Z83
SBR 1500	150	150									
Paracril 18-80			100	100							
Neoprene WRT					100	100					
Centhane S							100				
Hycar 4021								100			
SE33 (methyl vinyl siloxane)									100		
Linde W96 (methyl vinyl siloxane)										100	
Viton B											100
Zinc Oxide	3	3	5	5	5	5					
Stearic Acid	2	2	1.5	1.5	0.5	0.5	0.2				
Magnesium Oxide							4	4			15
Sulfur	1.75	1.75	1.5	1.5				0.5			
Altax			1.5	1.5							
Santocure	1.0	1.0									
Trimene Base								3			
Cadox TS Paste									1.3		
Cadox SG Paste										1.6	
LD 214											3
Neozone D	1	1			2	2					
Heliozone		1									
U.O.P. 88		3									
Agerite Rosin D	1	1									
Di Cup 40 C							4				
NA-22					0.5	0.5					
SRF Carbon Black					20	20					
MAF Carbon Black			60	60			30				
MT Carbon Black					30	30					20
Hi Sil 303									50		

Table B-1. (Concluded)

Compounding Ingredient	Parts by Weight										
	S119	S119B	N128	N128E	M72	M72E	Z72	Z74F	Z84	Z69 FCT	Z83
Santocel CS										40	
Red Iron Oxide										2	
Dioctyl Sebacate				20							
Trioctyl Phosphate						20					
HAF Carbon Black								30			
TOTAL PARTS	159.75	163.75	169.5	189.5	158	178	138.2	137.5	151.3	143.6	138

All compounds were cured for 30 minutes at 307°F except as follows:

Z69FCT - Press cured 20 minutes at 307°F; post cured 24 hours at 300°F in air oven.

Z84 - Press cured 10 minutes at 240°F; post cured 24 hours at 480°F in air oven.

Z83 - Press cured 30 minutes at 307°F; step cured in oven for one hour each at 212°, 250°, 300°, and 350°F; post cured 24 hours at 400°F in air oven.

Table B-2. EXPOSURE OF A POLYESTER ELASTOMER TO HIGH VACUUM AT VARIOUS TEMPERATURES[45]

Property Measured	Original	Exposed to Vacuum of 7.8×10^{-6} mm Hg for 5 Days at Room Temperature	400 F		500 F		600 F	
			Vacuum of 1.9×10^{-5} mm Hg for 5 Days	Air Oven for 5 Days	Vacuum of 1.4×10^{-5} mm Hg for 5 Days	Air Oven for 5 Days	Vacuum of 1.7×10^{-5} mm Hg for 5 Days	Air Oven for 5 Days
Hycar 4021 (Z74F)								
Tensile strength, psi	1420	1610	810	Too brittle to test				
Modulus, psi at 200 % E.	520	830	—					
Elongation, %	350	310	30					
Hardness, Shore A	58	56	89					
Strain, % E. at 400 psi	152	11[illegible]	Broke					
Change in weight, %	—	-0.6	-8.6	-13.5				

Table B-3. EFFECTS OF VACUUM AND OF VACUUM WITH ULTRAVIOLET RADIATION ON ELASTOMERS[46]*

Material	Type of Exposure**	Temperature, F	Exposure Time, hour	Weight Change, per cent	Tensile Strength			Breaking Elongation		
					Before Exposure, psi	After Exposure, psi	Change, per cent	Before Exposure, in./in.	After Exposure, in./in.	Change, per cent
Butyl	Vacuum	80	24	+ 0.10	2315	2616	+13.0	0.880	0.820	- 6.8
	Vacuum	80	96	+ 0.22	2315	2420	+ 4.5	0.880	0.845	- 4.0
	Vacuum	80	312	+ 0.09	2315	2441	+ 5.4	0.830	0.805	- 3.5
	Vacuum and ultraviolet	155	24	- 1.59	2315	2572	+11.1	0.880	0.790	-10.2
	Vacuum and ultraviolet	155	96	- 4.04	2315	2626	+13.4	0.880	0.755	-14.2
	Vacuum and ultraviolet	155	312	- 4.04	2315	2710	+17.1	0.880	0.650	-26.1

* Values are averages of two specimens.

** Maximum vacuum pressures on the order of 1×10^{-5} mm Hg.

Table B-4. RECIPES AND CURE SCHEDULES OF THE CHLOROBUTYL, CHLOROBUTYL-POLYCHLOROPRENE BLENDS AND CHLOROPRENES, USED IN THE IRRADIATION STUDIES[47]

Compound Data - Chlorobutyl, Chlorobutyl-Polychloroprene Blends and Chloroprene

	Compound 156-62	Compound 157-62	Compound 158-62	Compound 159-62
	Recipe, parts by weight			
Chlorobutyl HT-10-66	100	50	25	—
Neoprene WRT	—	50	75	100
HAF black	50	50	50	50
ZnO	—	5	5	5
Stearic acid	1	1	1	1
Tetramethyl thiuram disulfide	1	1	1	—
Benzothiazyl sulfide	—	2	2	—
MgO	0.5	2.5	3.25	8
	Cure Schedule			
Cure time, min.	40	40	40	40
Cure temperature, F	307	307	307	293

Table B-5. PHYSICAL PROPERTIES OF COMPOUND 156-62[47]

Base Elastomer-Chlorobutyl, Type HT-10-66

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	1494		223		500		62			
1. γ, Vac. 16 hrs., 70 F	1	6.4×10^6	1371	- 8	374	+68	243	-51	63	+ 1	+ 2	2
2. γ, Vac. 100 hrs., 70 F	14	6.1×10^7	582	-61	267	+20	187	-63	55	- 7	+ 2	3
3. γ+ UV, Vac.(2) 16 hrs., 95 F	15	5.7×10^6	1127	-25	309	+39	273	-45	63	+ 1	- 2	1
4. γ, Vac.(3) 100 hrs., 70 F	16	5.0×10^7	524	-65	269	+20	167	-67	57	- 5	-13	4
5. γ, Air 100 hrs., 70 F	17	6.1×10^7	539	-64	285	+28	163	-67	50	-12	+ 2	5
6. γ+ UV, Air(2) 100 hrs., 200 F	18	5.0×10^7	128	-91	92	-59	140	-72	52	-10	- 9	6

Table B-5. (Concluded)

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Combined radiation intended.

<u>Time effect</u>: Reaction is predominantly scission as noted by the decrease of hardness with time and of modulus after an initial increase.

<u>Atmosphere effect</u>: The scission seems to be slightly greater than crosslinking in air than in vacuo as indicated by hardness change.

<u>Type irradiation effect</u>: The specimens exposed to the combined radiation conditions did not show the surface decomposition that the straight gamma exposure specimens did.

<u>Observations</u>:
Condition 1, soft surfaces on speciments.
Condition 2, surface depolymerization to a tacky condition.
Condition 3, smoky discoloration on face toward lamp-tacky free surface.
Condition 4, surface depolymerization to a tacky condition.
Condition 5, surface depolymerization to a tacky condition.
Condition 6, irridescent discoloration on face toward lamp-tacky free surface. Specimens had lost elasticity.

Table B-6. PHYSICAL PROPERTIES OF COMPOUND 157-62[47]

Base Elastomer-Chlorobutyl- Polychloroprene Blend
Type-Chlorobutyl HT-10-66, Neoprene WRT (50:50)

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.[1]	100 % Modulus psi	100 % Modulus % Chg.[1]	Ultimate Elongation %	Ultimate Elongation % Chg.[1]	Hardness Duro A	Hardness Chg.[1]	Weight Change mg.	Rating
As-cured		0	1452		334		433		70			
1. γ, Vac. 16 hrs., 70 F	13	6.4×10^6	2058	+42	646	+ 93	223	-49	72	+ 2	+2	1
2. γ, Vac. 100 hrs., 70 F	14	6.1×10^7	963	-34	—	+350[3]	60	-86	82	+12	+8	4
3. γ, Vac.[2] 16 hrs., 95 F	15	5.7×10^6	987	-32	—	+102[3]	93	-79	75	+ 5	Nil	2
4. γ, Vac.[4] 100 hrs., 70 F	16	5.0×10^7	850	-42	—	+248[3]	73	-83	83	+13	+8	3
5. γ, Air 100 hrs., 70 F	17	6.1×10^7	1145	-21	—	+411[3]	67	-85	81	+11	+9	5
6. γ + UV, Air[2] 100 hrs., 200 F	18	5.0×10^7	148	-90	—	+450[3]	10	-98	86	+16	-7	6

Table B- (Concluded)

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Time effect: Cross-linking is the predominant reaction and is in proportion to the exposure time as was shown by comparison of Conditions 1 and 2.

Atmosphere effect: The reactions were similar in air as shown by comparison of the property changes in Conditions 2, 4, and 5.

Type irradiation effect: Comparison of 1 and 3, and 5 and 6 showed slightly more cross-linking induced by the combined radiation than by straight gamm

Observations: Condition 2, tabs of specimens had tacky spots on protected ends. Condition 3, smoky brown discoloration of face toward lamp. Condition 4, tabs of specimens had tacky spots on protected ends. Condition 5, tabs of specimens had tacky spots on protected ends. Condition 6, iridescent discoloration on face toward UV lamp. Slight blistering of specimens. Two specimens broke before test.

Table B-7. PHYSICAL PROPERTIES OF COMPOUND 158-6247

Base Elastomer-Chlorobutyl-Polychloroprene Blend
Type-Chlorobutyl HT-10-66, Neoprene WRT (25:75)

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg	Rating
As-cured		0	2144		420		383		72			
1. γ, Vac. 16 hrs., 70 F	13	6.4×10^6	1023	-52	332	- 21	217	-43	76	+ 4	+ 4	1
2. γ, Vac. 100 hrs., 70 F	14	6.1×10^7	1343	-37	--	+578(3)	47	-88	86	+14	+12	5
3. γ + UV, Vac.(2) 16 hrs., 95 F	15	5.7×10^6	1415	-34	--	+350(3)	75	-80	78	+ 6	+ 2	2
4. γ, Vac.(4) 100 hrs., 70 F	16	5.0×10^7	1168	-45	--	+340(3)	63	-84	86	+14	+13	3
5. γ, Air 100 hrs., 70 F	17	6.1×10^7	1542	-28	--	+672(3)	47	-88	86	+14	+16	6
6. γ + UV, Air(2) 100 hrs., 200 F	18	5.0×10^7	1052	-51	--	+402(3)	50	-87	89	+17	+ 3	4

Table B-7. (Concluded)

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Time effect: The compound showed an initial softening due to scission (by decrease in 100 per cent modulus condition), but this was balanced by cross-linking as shown by the hardness increase and the cross-linking became predominant as exposure time increased.

Atmosphere effect: Radiation in air apparently produced more cross-linking than radiation in vacuo as shown by comparison of Conditions 2, 4, and 5.

Type irradiation effect: Combined radiation in vacuo produced more cross-linking than straight gamma radiation (Condition 3 vs. 1), but examination of Conditions 5 and 6 revealed mixed changes in properties.

Table B-8. RECIPES AND CURE SCHEDULES OF THE CHLOROSULFONATED POLYETHYLENES USED IN THE IRRADIATION STUDIES[47]

Compound Data - Chlorosulfonated Polyethylenes

	Compound 130-62	Compound 131-62	Compound 132-62	Compound 134-62	Compound 136-62
	Recipe, parts by weight				
Hypalon 40	100	100	100	100	100
SRF black	20	20	20	40	40
Rosin	2.5	2.5	2.5	2.5	2.5
Tetrone A	1.0	1.0	1.0	1.0	1.0
MgO	30	30	30	30	30
Hydroquinone	—	3.3	3.3	—	4
	Cure Schedule				
Cure time, min	40	120	10	40	120
Cure temperature, F	293	293	293	293	293

Table B-9. PHYSICAL PROPERTIES OF COMPOUND 130-62[47]

Base Elastomer - Chlorosulfonated Polyethylene, Type - Hypalon 40

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	3235		941		277		80			
1. γ, Vac. 16 hrs., 70 F	3	7.8×10^6	3475	+ 7.4	1373	+ 45	280	+ 1.1	82	+ 2	+ 18	2
2. γ, Vac. 100 hrs., 70 F	4	4.9×10^7	2590	-20	2267	+141	110	-60	82	+ 2	+ 19	6
3. γ + UV Vac.(2) 16 hrs., 190 F	12	6.4×10^6	2253	-30	1275	+ 36	167	-40	85	+ 5	+ 27	3
4. γ + UV Vac.(2) 100 hrs., 250 F	10	6.1×10^7	3192	- 1.3	3265	+247	100	-64	85	+ 5	+ 10	7
5. γ, Air 100 hrs., 70 F	8	4.1×10^7	3062	- 5.3	2126	+126	130	-53	91	+11	+145	4
6. γ + UV Air(2) 100 hrs., 250 F	9	3.8×10^7	2977	- 8.0	2208	+135	120	-57	85	+ 5	+ 80	5
7. γ, Air 16 hrs., 70 F	3A	5.7×10^6	2362	-27	1005	+ 6.8	243	-12	83	+ 3	+ 21	1

(1) From as-cured value.

(2) Measured temperatures are uncertain.

Table B-9. (Concluded)

Time effect: The basic effect was cross-linking, increasing with exposure time.

Atmosphere effect: The modulus increase was greater in vacuo than in air. Tensile changes were mixed as were the changes in ultimate elongation. The specimens gained weight, markedly so in air. The effect of the UV was to increase the vacuum exposure weight gain and decrease the size of the weight gain in air.

Type irradiation effect: After 16 hours the mixed radiation in vacuo showed a greater effect on hardness, ultimate elongation and tensile, and a lesser effect on modulus than straight gamma in vacuo. After 100 hours the mixed radiation effect on tensile was less, the effect on modulus and hardness greater, and the effect on elongation the same as for straight gamma. In air the results were similar for mixed and straight gamma radiation.

Observations: Condition 2, specimens broke out of or close to end of reduced section. Condition 3, slight discoloration of face toward UV lamp. Condition 4, very slight discoloration of face toward UV lamp. Condition 7, very slight discoloration of face toward UV lamp.

Table B-10. PHYSICAL PROPERTIES OF COMPOUND 131-62[47]

Base Elastomer - Chlorosulfonated Polyethylene, Type - Hypalon 40

Nominal Irradiated Condition	Can No.	Gamma Dose	Tensile Strength		100 % Modulus		Ultimate Elongation		Hardness		Weight Change	Rating
		r.	psi	% Chg.(1)	psi	% Chg.(1)	%	% Chg.(1)	Duro A	Chg.(1)	mg.	
As-cured		0	3063		1001		330		84			
1. γ, Vac. 16 hrs., 70 F	3	7.8×10^6	3022	-1.3	1404	+ 40	257	-22	86	+2	+ 22	2
2. γ, Vac. 100 hrs., 70 F	4	4.9×10^7	3316	+9.7	2002	+100	205	-38	86	+2	+ 14	4
3. γ + UV Vac.(2) 16 hrs., 190 F	12	6.4×10^6	3195	+4.3	1374	+ 37	213	-36	84	Nil	+ 20	3
4. γ + UV Vac.(2) 100 hrs., 250 F	10	6.1×10^7	3099	+1.1		141(3)	93	-71	84	Nil	- 7	6
5. γ, Air 100 hrs., 70 F	8	1.1×10^7	2994	-0.9	2534	+ 80	127	-62	90	+6	+147	4
6. γ + UV Air(2) 100 hrs., 250 F	9	3.8×10^7	3849	+26	2867	+104	140	-46	88	+4	+ 95	5
7. γ, Air 16 hrs., 70 F	3A	5.7×10^6	3151	+2.9	976	- 2.5	363	+10	85	+1	+ 30	1

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

Table B-10. (Concluded)

Time effect: The radiation effects, essentially cross-linking, grow more severe as the exposure time is increased (Condition 1 vs. 2).

Atmosphere effect: Except for elongation change at 100 hours the gamma radiation effects were more severe in vacuo than in air. In combined radiation the effect was mixed, the increase in 100 per cent modulus and decrease in ultimate elongation being greater in vacuo and the increase in tensile strength and hardness being greater in air. Most specimens gained weight markedly in air. The effect of UV was to increase the weight gains in vacuum exposure and decrease the weight gains in air.

Type irradiation effect: The difference between the effects of combined radiation and straight gamma radiation were inconsistent.

Observations: Condition 4, moderate discoloration on face toward UV lamp. Condition 5, very slight discoloration. Condition 6, very slight discoloration on face toward UV lamp. Condition 7, slight iridescence on face of specimens.

Table B-11. PHYSICAL PROPERTIES OF COMPOUND 132-62[47]

Base Elastomer - Chloroaulfonated Po... ...yle..e, Type - Hypalon 40

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Modulus Strength psi	Modulus Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	3312		878		330		82			
1. γ, Vac. 16 hrs., 70 F	3	7.8×10^6	3274	- 1.2	1514	+ 72	223	-32	83	+1	+20	1
2. γ, Vac. 100 hrs., 70 F	4	4.9×10^7	3425	+ 3.7	2155	+145	170	-48	85	+3	+18	3
3. γ + UV, Vac.(2) 16 hrs., 190 F	12	6.4×10^6	3112	- 5.8	1644	+ 87	167	-49	85	+3	+18	2
4. γ + UV, Vac.(2) 100 hrs., 250 F	10	6.1×10^7	2617	-21	—	+462(3)	53	-84	83	+1	- 3	6
5. γ, Air 100 hrs., 70 F	8	4.1×10^7	2558	-22	2364	+169	113	-66	91	+9	+30	4
6. γ + UV, Air(2) 100 hrs., 250 F	9	3.8×10^7	3120	- 5.5	2677	+205	114	-66	85	+3	+79	5

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

Table B-11. (Concluded)

Time effect: Cross-linking in vacuo became more severe as exposure time increased (Conditions 1 vs. 2 and 3 vs. 4).

Atmosphere effect: Air exposure was more severe than vacuo in gamma radiation but the reverse was true in mixed radiation (Conditions 2 vs. 5 and 3 vs. 6). Most specimens gained weight. The weight gain was markedly more pronounced in air than vacuo and was decreased by the addition of UV radiation and heat.

Type irradiation effect: Mixed radiation produces more cross-linking than gamma radiation and the effect is more pronounced in vacuo than in air (Conditions 2 vs. 4 and 5 vs. 6).

Observations: Condition 3, discoloration on face toward UV lamp. Condition 4, slight discoloration on face toward UV lamp. Condition 6, discoloration on face toward UV lamp.

Table B-12. PHYSICAL PROPERTIES OF COMPOUND 134-62[47]

Base Elastomer - Chlorosulfonated Polyethylene, Type - Hypalon 40

Nominal Irradiated Condition	Can No.	Gamma Dose	Tensile Strength		100 % Modulus		Ultimate Elongation		Hardness		Weight Change	Rating
		[illegible]	psi	% Chg.(1)	psi	% Chg.(1)	%	% Chg.(1)	Duro A	Chg.(1)	mg.	
As-cured		0	3190		1567		207		88			
1. γ, Vac. 16 hrs., 70 F	3	7.8×10^6	3372	+ 4.1	2567	+ 64	143	-30	87	-1	+ 18	1
2. γ, Vac. 100 hrs., 70 F	4	4.9×10^7	3414	+ 7.0	—	+150(3)	87	-58	89	+1	- 15	5
3. γ + UV, Vac.(2) 16 hrs., 190 F	12	6.4×10^6	1938	-29	—	+ 30(3)	95	-54	88	Nil	+ 19	2
4. γ + UV, Vac.(2) 100 hrs., 250 F	10	6.1×10^7	3108	- 2.6	—	+231(3)	60	-71	89	+1	+ 6	7
5. γ, Air 100 hrs., 70 F	8	4.1×10^7	3553	+11	—	+183	80	-44	94	+6	+117	6
6. γ + UV, Air(2) 100 hrs., 250 F	9	3.8×10^7	3692	+16	—	+125(3)	83	-56	91	+3	+ 62	4
7. γ, Air 16 hrs., 70 F	3A	5.7×10^6	900	-72	796	- 48	110	-48	88	Nil	+ 19	3

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

Table B-12. (Concluded)

Time effect: The compound when irradiated in vacuo underwent an increase in tensile and modulus and decrease in elongation with time. In air it passed through an initial period which in the modulus and tensile strength decreased as well as the elongation. This indicated a period of chain scission.

Atmosphere effect: The reaction produced by exposure in vacuo was, in general, more severe than that in air. The reaction in vacuo, at all periods, and air, for long periods, seemed to be predominantly cross-linkage although the material irradiated in air underwent an initial chain scission period. The weight changes were greater in air than in vacuo and were decreased by the addition of the UV radiation.

Type irradiation effect: The difference in effect between combined radiation and gamma radiation was inconsistent.

Observations: None

Table B-13. PHYSICAL PROPERTIES OF COMPOUND 136-62[1]

Base Elastomer - Chlorosulfonated Polyethylene Type - Hypalon 40[47]

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(2)	100 % Modulus psi	100 % Modulus % Chg.(2)	Ultimate Elongation %	Ultimate Elongation % Chg.(2)	Hardness Duro A	Hardness Chg.(2)	Weight Change mg.	Rating
As-cured		0	3400		1785		210					
7. γ, Air 16 hrs., 70 F	3A	5.7×10^6	1217	-64	789	-56	203	-3.3			+26	

(1) Although lack of time permitted exposure of this compound to only one condition, it was included to show the effect of the addition of antirad (to compound 134-62).

(2) From as-cured value.

Table B-14. ELASTOMERS TESTED FOR EFFECTS OF HIGH TEMPERATURES IN A VACUUM[9]

Elastomers

Silicone (DC 651, 916, 2071), a polysiloxane high polymer useful over the temperature range of -130°F to 500°F.

Adiprene ("L" and "C"), a urethane polymer useful over the temperature range of -65°F to 175°F.

Buna N, an acrylonitrile-butadiene polymer useful over temperature range of -60°F to 200°F.

Butyl (K-121 and K-1330), an isobutylene isoprene polymer useful over temperature range of -70°F to 250°F.

Neoprene, a chloroprene polymer useful over the temperature range of -60°F to 200°F.

Viton A-U-74, a copolymer of vinylidene fluoride and hexafluoropropylene useful over the temperature range of -47°F to 500°F.

Silicon sponge, closed cell recommended for use from -100°F to 480°F.

Table B-15. EFFECT OF LOW PRESSURE AND HIGH TEMPERATURES ON SPACE VEHICLE ELASTOMERS[9]

Material	Test Data					
	Conditions		Sample Size & No.	Property	Result	Comments
Silicone DC 2071	Temperature Ultimate pressure Time at pressure	450 F 6×10^{-4} mm 3 hours	3 Standard tensile specimens	a) Tensile strength b) Hardness c) Elongation	a) No significant change in tensile strength b) No change in hardness c) 18.4% Decrease in elongation	The test results for the silicone rubbers were very widely scattered and variant demonstrating a need for large sample lots to indicate more conclusively any trends in physical-property change.
Silicone DC 916	Temperature Ultimate pressure Time at pressure	450 F 1.2×10^{-4} 4-1/2 hours	2 Standard tensile specimens	Same as above	a) Test void - results widely variant b) 2% Increase in hardness c) 4.2% Decrease in elongation	Ditto
Silicone DC 651	Temperature Ultimate pressure Time at pressure	450 F 1.2×10^{-4} 4-1/2 hours	2 Standard tensile specimens	Same as above	a) No significant change in tensile strength b) No change in hardness c) 10.2% Decrease in elongation	"
Buna-N	Temperature Ultimate pressure Time at pressure	300 F 1.2×10^{-3} 5 hours	3 Standard tensile specimens	Same as above	a) Tensile tests inconclusive b) 13.5% Increase in hardness c) 7.8% Decrease in elongation	Hardness and elongation differences consistent tensile data widely scattered.
Neoprene	Temperature Ultimate pressure Time at pressure	300 F 5×10^{-4} 3 hours	3 Standard tensile specimens	Same as above	a) 34.2% Increase in tensile strength b) 23% Increase in hardness c) 6.8% Decrease in elongation	Tensile, hardness, and elongation changes consistent.
Adiprene	Temperature Ultimate pressure Time at pressure	200 F 1.1×10^{-2} 5 hours	3 Standard tensile specimens	Same as above	a) No significant change in tensile strength b) No change in hardness c) 7.2% Increase in elongation	Poor ultimate pressure obtained; rerun of additional samples necessary.
Silicone Sponge MCI 4546-GR.42	Temperature Ultimate pressure Time at pressure	450 F 8×10^{-5} 3-1/2 hours	3 Specimens 2"x2"x3"	a) Compression deflection b) Water absorption	a) Test results inconclusive	
Adiprene C	Temperature Ultimate pressure Time at pressure	300 F $9/2 \times 10^{-4}$ 6 hours	[illegible] Standard tensile specimens	a) Tensile strength b) Hardness c) Elongation	a) Increase of 37.7% in tensile strength b) 8.3% Increase in hardness c) No significant change in elongation	Tensile and hardness data consistent.

Table B-15. (Concluded)

Material	Test Data: Conditions	Sample Size & No.	Property	Result	Comments
Butyl K-1210	Temperature 300 F Ultimate pressure 8.4×10^{-4} Time at pressure 5.5 hours	6 Standard tensile specimens	a) Tensile strength b) Hardness c) Elongation	a) 7.7% Decrease in tensile strength b) 1.9% Increase in hardness c) 11.9% Decrease in elongation	Yellowish condensate observed in cold trap. Elongation data consistent tensile strength data scattered.
Viton A U-74	Temperature 400 F Ultimate pressure 5.5×10^{-4} Time at pressure 6.5 hours	2 Standard tensile specimens	Same as above	a) 12.3% Decrease in tensile strength b) 1.4% Increase in hardness c) 5.5% Decrease in elongation	Insufficient samples for significant results.
Butyl K-1330	Temperature 250 F Ultimate pressure 2.5×10^{-4} Time at pressure 5 hours	6 Standard tensile specimens	Same as above	a) 7.3% Increase in tensile strength b) 7.7% Increase in hardness c) 6.5% Decrease in elongation	Elongation data consistent tensile data scattered.

Table B-16. EXPOSURE OF VITON-B TO HIGH VACUUM AT VARIOUS TEMPERATURES[45]

Property Measured	Original	Exposed to Vacuum of 7.8 x 10^{-6} mm Hg for 5 Days at Room Temperature	400 F: Vacuum of 1.9 x 10^{-5} mm Hg for 5 Days	400 F: Air Oven for 5 Days	500 F: Vacuum of 1.4 x 10^{-5} mm Hg for 5 Days	500 F: Air Oven for 5 Days	600 F: Vacuum of 1.7 x 10^{-5} mm Hg for 5 Days	600 F: Air Oven for 5 Days
Tensile strength, psi	2610	2630	2280	2270	2140	620	620	220
Modulus, psi at 200 per cent elongation	1300	1030	1810	1000	1970	520	570	--
Elongation, per cent	320	340	240	370	210	410	240	110
Hardness, Shore A	74	72	75	64	75	75	77	83
Strain, per cent elongation at 400 psi	107	96	89	125	82	171	123	Broke
Change in weight, per cent	--	-0.06	-0.07	-1.1	-2.1	-6.8	-5.5	-18.8

Table B-17. RECIPES AND CURE SCHEDULES OF THE FLUOROELASTOMERS (VITON A) USED IN THE IRRADIATION STUDIES[47]

Compound Data - Fluoroelastomer

	Compound 150-62	Compound 151-62	Compound 152-62
	Recipe, parts by weight		
Viton A	100	100	100
MT black	25	60	—
GPF black	—	—	60
MgO	15	15	15
HMDAC	1.5	1.5	1.25

Cure Schedule

All compounds were press cured for 30 minutes at 300 F, and post cured for 28 hours at 400 F.

Table B-18. PHYSICAL PROPERTIES OF COMPOUND 150-6247

Base Elastomer - Fluoroelastomer, A Copolymer of Vinylidene Fluoride and Hexafluoropropylene

Type - Viton A

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	1835		1446		123		88			
2. γ, Vac. 100 hrs., 70 F	14	6.1×10^7	1299	-29	—	+199(3)	30	-76	93	+5	+1	3
3. γ + UV, Vac.(2) 16 hrs., 95 F	15	5.7×10^6	1512	-18	—	+ 35(3)	77	-37	88	Nil	Nil	1
4. γ, Vac.(4) 100 hrs., 70 F	16	5.0×10^7	1946	+ 6.0	—	+ 92(3)	67	-46	91	+3	Nil	2
5. γ, Air 100 hrs., 70 F	17	6.1×10^7	1600	-13	—	+381(3)	23	-81	88	Nil	+2	5
6. γ + UV, Air(2) 100 hrs., 200 F	18	5.0×10^7	1461	-20	—	+304(3)	25	-72	91	+3	-6	4

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Table B-18. Concluded)

Time effect: Cross-linking increases with the increase in radiation dosage.

Atmosphere effect: Irradiation in air caused more cross-linking than in vacuo. Weight changes were generally insignificant.

Type irradiation effect: Combined irradiation caused more cross-linking than straight gamma radiation.

Observations: Condition 3, brownish to smoky grey discoloration on face toward UV lamp. Condition 6, iridescent discoloration of face toward UV lamp.

Table B-19. PHYSICAL PROPERTIES OF COMPOUND 151-62[47]

Base Elastomer - Fluoroelastomer A Copolymer of Vinylidene Fluoride and Hexafluoropropylene

Type - Viton A

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	1867		696		177		78			
1. γ, Vac. 16 hrs., 70 F	13	6.4×10^6	1833	- 1.8	1435	+106	113	-36	78	Nil	+3	2
2. γ, Vac. 100 hrs., 70 F	14	6.1×10^7	2010	+ 7.6	—	+345(3)	65	-63	84	+6	+2	5
3. γ + UV, Vac.(2) 16 hrs., 95 F	15	5.7×10^6	2168	+16	1333	+ 92	137	-23	78	Nil	+1	1
4. γ, Vac.(4) 100 hrs., 70 F	16	5.0×10^7	1658	-12	—	+258(3)	67	-62	85	+7	Nil	4
5. γ, Air 100 hrs., 70 F	17	6.1×10^7	1977	+ 5.9	—	+374(3)	60	-66	84	+6	+4	6
6. γ + UV, Air(2) 100 hrs., 200 F	18	5.[illegible] x 10^7	1738	- 6.9	—	+235(3)	73	-41	85	+7	-4	3

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Table [illegible] (Concluded)

<u>Time effect</u>: Cross-linking starts immediately and becomes more severe as exposure time is increased (Condition 1 vs. 2).

<u>Atmosphere effect</u>: At room temperature the changes produced by air exposure are somewhat greater than those produced by vacuo exposure. The situation is reversed at the elevated temperature of the combined irradiation. The weight gains are not large enough to be significant.

<u>Type irradiation effect</u>: Combined irradiation produces less cross-linking than straight gamma radiation as particularly shown in the 100 per cent modulus figures (Condition 1 vs. 3 and 5 vs. 6).

<u>Observations</u>: Condition 3, brownish discoloration on face toward lamp. Condition 6, iridescent coloration on face toward UV lamp.

Table B-20. PHYSICAL PROPERTIES OF COMPOUND 152-62[47]

Base Elastomer - Fluoroelastomer, A Copolymer of Vinylidene Fluoride and Hexafluoropropylene

Type - Viton A

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	1300				90		95			
1. γ, Vac. 16 hrs., 70 F	13	6.4×10^6	1884	+ 45		+146(3)	53	-41	94	-1	+5	2
2. γ, Vac. 100 hrs., 70 F	14	6.1×10^7	2459	+ 89		+153(3)	30	-67	96	+1	+6	3
3. γ + UV, Vac.(2) 16 hrs., 95 F	15	5.7×10^6	1670	+ 28		+ 83(3)	63	-30	93	-2	-1	1
4. γ, Vac.(4) 100 hrs., 70 F	16	5.0×10^7	2321	+ 79		+222(3)	50	-44	95	Nil	+2	4
5. γ, Air 100 hrs., 70 F	17	6.1×10^7	2593	+100		+495(3)	30	-67	95	Nil	+8	5
6. γ + UV, Air(2) 100 hrs., 200 F	18	5.0×10^7	2048	+ 65		+610(3)	20	-78	95	Nil	-3	6

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Table B-10. (Concluded)

<u>Time effect</u>: The cross-linking effect caused by radiation was increased by increased exposure time.

<u>Atmosphere effect</u>: Examination of Condition 2 and 5 reveals that greater cross-linking took place in air rather than in vacuo. Weight changes were small and generally gains. The effect of ultraviolet was to decrease the weight gains or cause small losses (Conditions 3 and 6).

<u>Type irradiation effect</u>: Combined radiation caused less cross-linking in vacuo as evidenced by the effect on the tensile strength and modulus (Condition 1 vs. 3). The reverse was true in air as shown by changes in modulus and 100 per cent elongation (Condition 5 vs. 6).

<u>Observations</u>: Condition 3, shiny brownish yellow discoloration on face toward UV lamp. Condition 6, iridescent discoloration with smoky deposit on face toward UV lamp.

Table B-21. TEST ENVIRONMENT AND RESULTS OF STATIC TEST: NITRILE RUBBER[6]

Material Trade Name	Radiation Exposure: Gamma [ergs/gm(C)]	Radiation Exposure: Neutrons (n/cm²) Thermal	Neutrons E>2.9 Mev	Neutrons E>8.1 Mev	Sample Weight: Original, gm	Sample Weight: Change, gm	Tensile Strength(a) (psi): at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Ultimate Elongation, per cent	Temperature: Average, (F)	Temperature: Figure No.(c)	Pressure: Average, (torr)	Pressure: Figure No.(c)
Buna N (RA30760)	0	0 (control specimens) August 1962	0	0		—	99 103 101 101 101/1.9	137 141 134 140 138/3.4	170 185 168 173 174/10.0	2511 2679 2598 2732 2630/108	690 680 670 700 685/14.6ª	77	—	760	
	1.7(9)	6.5(12) (vacuum irradiation) August 1962	1.9(13)	7.3(11)	3.8288 3.8104 3.8988 3.9816	+0.0020 +0.0020 +0.0012 +0.0012	(b) 14 14 13 13.7/0.6	(b) 21 20 20 20.3/0.6	(b) — 30 29 29.5/0.9	(b) 197 207 203 203/5.9	(b) 440 460 450 450/11.8	80	D-8	5(-6)	
	7.0(9)	8.1(12) (vacuum irradiation) August 1962	8.[illegible](13)	3.1(12)	3.8052 3.9753 3.8066 3.8906	-0.0006 +0.0004 +0.0014 +0.0006	25 — 22 22 23/1.8	46 — 38 39 41/4.7	87 — 81 71 80/9.4	212 195 210 180 199/15.[illegible]	180 — 220 200 200/23.6	80	D-8	5(-6)	
	0	0 (control specimens) February 1963	0	0	—	—	138 122 140 112 128/13.6	193 161 168 156 170/17.8	— 239 224 210 224/17.1	— 2583 2447 2034 2355	— 672 660 620 647	—	—	—	
	0	0 (vacuum controls) February 1963	0	0	3.8931 3.8703 3.8334 3.8295 3.8063	+0.0020 -0.0025 -0.0025 -0.0028 -0.0026	— 133 112 141 129 129/14.1	177 167 157 180 169 170/9.9	221 222 214 230 219 221/6.9	2553 2400 2646 2730 2011 2468/309	650 635 650 570 575 636/40.8	—	—	—	
	0	0 (control specimens May 1962	0	0	—	—	109/11/4	160/6.4/5	211/8.6/5	2459/496/5	643/51/5ª	—	—	—	
	1.87(9)	(air irradiation) May 1962			—	—	159/30/5	220/23/5	348/12/5	2174/630/5	391/67/5	—	—	—	
	2.06(10)	(air irradiation) May 1962			—	—	1177/129/4	1999/52/4	3495/233/4	3512/206/5	100/4.9/4	—	—	—	

(a) Average value/standard deviation on an individual basis/number of samples.

(b) No tensile values were obtained for this specimen.

(c) Applies to the original reference.

Table B-22. CHANGES IN PROPERTIES OF NITRILE RUBBER IRRADIATED IN VACUUM AND IN AIR[6]

Category	Trade Name	Gamma Dose [ergs/gm(C)]	Vacuum (torr)	Specimen Configuration	Measured Property	Per Cent Change in Measured Property
Elastomers	Buna N (RA 30760)	0 Vacuum Controls	1×10^{-6}	Tensile (ASTM-D-412-51T, Die C)	Ultimate tensile strength	0
					Ultimate elongation	0
					Weight change	0
		1.7×10^{9}	5×10^{-6}	Tensile (ASTM-D-412-51T, Die C)	Ultimate tensile strength	-91.5
					Ultimate elongation	-34.3
					Weight change	0
		7.0×10^{9}	5×10^{-6}	Tensile (ASTM-D-412-51T, Die C)	Ultimate tensile strength	-92
					Ultimate elongation	-71
					Weight change	0
		1.9×10^{9}	Air irradiated	Tensile (ASTM-D-412-51T, Die C)	Ultimate tensile strength	-11.6
					Ultimate elongation	-39
		2.1×10^{10}	Air irradiated	Tensile (ASTM-D-412-51T, Die C)	Ultimate tensile strength	+43
					Ultimate elongation	-84.5

Table B-23. EXPOSURE OF NITRILE RUBBER VULCANIZATES TO HIGH VACUUM AT VARIOUS TEMPERATURES[45]

Property Measured	Original	Exposed to Vacuum of 10^{-5} mm Hg for 56 Days at Room Temperature	158 F		212 F		300 F	
			Vacuum of 8×10^{-5} mm Hg for 7 Days	Air Oven for 7 Days	Vacuum of 7.8×10^{-6} mm Hg for 5 Days	Air Oven for 5 Days	Vacuum of 2.1×10^{-6} mm Hg for 5 Days	Air Oven for 5 Days
				Unplasticized Compound (N128)[1]				
Tensile strength, psi	2680	2470	2670	2710	2910	2830	2270	—
Modulus, psi at 200 per cent elongation	1980	—	—	—	—	—	—	—
Elongation, per cent	260	230	235	255	230	230	170	—
Hardness, Shore A	72	74	75	75	72	74	79	—
Strain, per cent elongation at 400 psi	82	82	72	63	75	70	55	—
Low temperature flexibility, ASTM D1043, T_{200}, F	-28	-29	-31	-29	—	—	-25	—
Weight change, per cent	—	+1.2	-0.5	—	-2.6	-0.8	-2.8	-3.2

Table B-23. (Concluded)

Property Measured	Original	Exposed to Vacuum of 10^{-5} mm Hg for 56 Days at Room Temperature	Vacuum of 8×10^{-5} mm Hg for 7 Days	Air Oven for 7 Days	Vacuum of 7.8×10^{-6} mm Hg for 5 Days	Air Oven for 5 Days	Vacuum of 2.1×10^{6} mm Hg for 5 Days	Air Oven for 5 Days
Plasticized Compound (N128E)[1]								
Tensile strength, psi	1370	1480	2020	1580	2160	1830	1790	Too brittle to test
Modulus, psi at 300 per cent elongation	850	840	1290	950	1870	1460	—	Too brittle to test
Elongation, per cent	410	430	385	340	330	360	210	Too brittle to test
Hardness, Shore A	57	55	66	59	68	56	76	Too brittle to test
Strain, per cent elongation at 400 psi	209	200	141	206	124	116	79	Too brittle to test
Low temperature flexibility, ASTM D1043, T_{200}, F	-56	-53	-36	[illegible]	—	—	-31	Too brittle to test
Weight change, per cent	—	+0.2	-9.1	—	-9.3	-1.9	-10.2	-9.0

(1) See Table A-1 for formulation.

per cent	—	+0.2	-9.1	—	-9.3	-1.9	-10.2	-9.0

(1) See Table A-1 for formulation.

TABLE B-24. TEST ENVIRONMENT AND RESULTS OF STATIC TEST: NEOPRENE RUBBER

Material Trade Name	Radiation Exposure: Gamma [ergs/gm(C)]	Neutrons (n/cm²): Thermal	Neutrons (n/cm²): E>2.9 Mev	Neutrons (n/cm²): E>8.1 Mev	Sample Weight: Original, gm	Sample Weight: Change, gm	Tensile Strength[a] (psi): at 25% Elongation	Tensile Strength[a] (psi): at 50% Elongation	Tensile Strength[a] (psi): at 100% Elongation	Tensile Strength[a] (psi): Ultimate	Ultimate Elongation, percent	Temperature: Average, (F)	Temperature: Figure No.[c]	Pressure: Average (torr)	Pressure: Figure No.[c]
Neoprene (RA24160)	0	0 (control specimens) (for vacuum test)	0	0	—	—	135 141 131 — 150 139/9.2	233 222 222 227 — 226/5.3	415 384 35? — — 384/36.0	3306 3182 3005 2878 3300 3134/227	445 450 420 390 425 426/25.8	77	—	760	
	1.9(9)	6.7(12) (vacuum irradiation) August 1962	2.9(13)	8.0(11)	4.9741 5.2147 5.0148 5.1056	— +0.0093 +0.0100 +0.0100	19 21 18 18 19/1.5	28 32 33 36 32/3.9	— 64 63 68 65/3.0	237 158 197 172 191/38.4	260 190 220 200 218/34.0	80	D-7	5(-6)	
	5.4(9)	9.2(12) (vacuum irradiation) August 1962	9.8(13)	3.7(12)	5.0792 5.0785 4.9626 4.8844	+0.0400 +0.0385 +0.0361 +0.0276	31 30 29 35 31/2.9	75 76 66 72 72/4.9	— — — — —	115 130 147 142 134/15.5	115 80 115 80 98/17.0	80	D-7	5(-6)	
	0	0 (control specimens) May 1962	0	0	—	—	153/12.9/5	220/8.6/5	392/18.9/4	3297/244/5	454/29.6/5	—	—	—	
	1.8(9)	(air irradiation) May 1962			—	—	186/24.9/5	316/26.2/5	628/46.4/5	2769/224/5	265/21.5/5	—	—	—	
	2.06(10)	(air irradiation)			—	—	—	—	—	203/40/5	35/6.4/5	—	—	—	

(a) Average value/standard deviation on an individual basis/number of samples.

(b) No tensile values were obtained for this specimen.

(c) Applies to the original reference.

TABLE B-25. CHANGES IN PROPERTIES OF ELASTOMERS IRRADIATED IN VACUUM AND IN AIR[6]

Category	Trade Name	Gamma Exposure, ergs g^{-1}(c)	Vacuum, torr	Specimen Configuration	Measured Property	Per Cent Change in Measured Property
Elastomers	Neoprene (RA 24160)	1.9×10^9	5×10^{-6}	Tensile (ASTM-D-412-51T, Die C)	Ultimate tensile strength	-94
					Ultimate elongation	-49
					Weight change	0
		5.4×10^9	5×10^{-6}	Tensile (ASTM-D-412-51T, Die C)	Ultimate tensile strength	-9[illegible]
					Ultimate elongation	-77
					Weight change	0

Table B-26. RECIPES AND CURE SCHEDULES OF THE POLYCHLOROPRENES USED IN THE IRRADIATION STUDIES[47]

Compound Data - Polychloroprenes

	Compound 138-62	Compound 139-62	Compound 140-62	Compound 159-62	Compound 161-62
	Recipe, parts by weight				
Neoprene WRT	100	100	100	100	100
SRF black	35	35	35	—	—
HAF black	—	—	—	50	50
[illegible]	5	5	5	5	5
Stearic acid	1	1	1	1	1
MgO	4	4	4	8	8
Hydroquinone	—	2.0	5.0	—	—
Tetramethyl thiuram disulfide	—	—	—	1	1
Benzothiazyl sulfide	—	—	—	2	2
	Cure Schedule				
Cure time, min.	40	40	40	40	20
Cure temperature, F	293	293	293	293	293

Table B-27. PHYSICAL PROPERTIES OF COMPOUND 138-62[47]

Base Elastomer - Polychloroprene, Type - Neoprene WRT

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg	Rating
As-cured		0	2303		187		537		60			
1. γ, Vac. 16 hrs., 70 F	3	7.8×10^6	2731	+ 19	540	+ 189	247	- 54	69	+ 9	+10	1
2. γ, Vac. 100 hrs., 70 F	4	4.9×10^7	2140	- 7	—	+ 1386(3)	77	- 86	84	+24	+21	5
3. γ + UV, Vac.(2) 16 hrs., 190 F	12	6.4×10^6	855	- 64	—	+ 408(3)	90	- 83	75	+15	+16	2
4. γ + UV, Vac.(2) 100 hrs., 250 F	10	6.1×10^7	1700	- 26	—	+ 2356(3)	37	- 93	88	+28	+10	6
5. γ, Air 100 hrs., 70 F	8	4.1×10^7	579	- 75	—	+ 1245(3)	23	- 96	88	+28	+67	4
6. γ + UV, Air(2) 100 hrs., 250 F	9	3.8×10^7	1265	- 45	—	+ 1007(3)	57	- 89	86	+26	+53	3

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

Table B-27. (Concluded)

<u>Time effect</u>: The cross linking began immediately and increased very much with incr in exposure time. This was shown by the behavior of all properties checked (Condition 1 vs. 2 and 3 vs. 4), except the tensile strength.

<u>Atmosphere effect</u>: Irradiation in air produced a greater change in tensile strength than radiation in vacuo. The difference in change was greater at room temperature than at the elevated temperature of the combined irradiation conditions. The modulus change was somewhat greater in vacuo than air at room temperatures and very much greater at the elevated temperature of combined radiation. Hardness and elongation changes were mixed. All specimens gained weight, markedly so in air.

<u>Type irradiation effect</u>: In vacuo the combined radiation effects were markedly more severe than the straight gamma radiation. The combined radiation in air was apparently less severe than straight gamma radiation.

<u>Observations</u>: Condition 4, slight discoloration on face toward UV lamp. Condition 5, slight discoloration of specimens, whitish deposit on protected tabs. Condition 6, discoloration on face toward UV lamp.

Table B-28. PHYSICAL PROPERTIES OF COMPOUND 139-62[47]

Base Elastomer - Polychloroprene, Type - Neoprene WRT

Nominal Irradiation Conditions	Spec. No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	2149		224		516		68			
1. γ, Vac., 16 hrs., 70 F	3	[illegible].5 x 10^6	2110	- 13	461	+ 106	260	- 50	69	+ 1	+ 5	[illegible]
2. γ, Vac. 100 hrs., 70 F	4	4.9 x 10^7	1357	- 36	933	+ 317	123	- 75	[illegible]	+ 4	+11	4
3. γ + UV, Vac.(2) 16 hrs., 190 F	12	6.4 x 10^6	1394	- 35	592	+ 16[illegible]	167	- 67	71	+ 3	+10	3
4. γ + UV, Vac.(2) 100 hrs., 250 F	10	6.1 x 10^7	965	- 55	—	+ 978(3)	40	- 93	[illegible]	+ 5	Nil	7
5. γ, Air, 100 hrs., 70 F	8	4.1 x 10^7	1016	- 53	—	+ 827(3)	70	- 86	74	+ 6	+72	6
6. γ + UV, Air(2) 100 hrs., 250 F	9	3.8 x 10^7	1109	- 48	—	+ 386(3)	63	- 88	73	+ 5	[illegible]	5
7. γ, Air 16 hrs., 70 F	3A	[illegible].7 x 10^6	2526	+ 18	495	+ 121	290	- 44	70	+ 2	+13	[illegible]

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

Table B-23. (Concluded)

<u>Time effect</u>: The cross-linking began immediately with exposure and increased markedly as exposure time increased. This was shown by the behavior of the 100 per cent modulus, ultimate elongation, and hardness changes (1 vs. 2, 3 vs. 4, and 7 vs. 5).

<u>Atmosphere effect</u>: During short periods of irradiation (Condition 1 vs. 7), irradiation in air produced slightly greater changes in the physical properties than irradiation in vacuo. This difference became more marked as the irradiation time was increased. However, during combined irradiation (Condition 4 and 6), the effect was reversed and irradiation in vacuo produced greater changes than irradiation in air. All conditions showed slight increases with larger increases being produced by irradiation in air and by combined radiation.

<u>Type irradiation effect</u>: The combined radiation produced more severe effects in vacuo than the straight gamma radiation (Conditions 1 vs. 3 and 2 vs. 4). In air the differences were slight but larger changes were produced by straight gamma in tensile strength and modulus and very slightly larger changes were produced in the ultimate elongation by combined radiation.

<u>Observations</u>: Condition 4, discoloration of specimens on face toward ultraviolet lamp. Condition 5, slight discoloration of specimens. Condition 6, slight discoloration of specimens.

Table B-29. PHYSICAL PROPERTIES OF COMPOUND 1[illegible]0-6247

Base Elastomer - Polychloroprene, Type Neoprene WRT

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	300 % Modulus psi	300 % Modulus Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	1835		239		517		71			
1. γ, Vac. 16 hrs., 70 F	3	7.8 x 10^6	2330	+27	491	+ 105	283	-46	69	- 2	+ 4	2
2. γ, Vac 100 hrs., 70 F	4	4.9 x 10^7	1243	-32	871	+ 263	123	-76	77	+ 6	+11	4
3. γ + UV, Vac.(2) 16 hrs., 1[illegible]0 F	12	6.4 x 10^6	1097	-40	606	+ 154	163	-69	73	+ 2	+ 3	3
4. γ + UV, Vac.(2) 100 hrs., 250 F	10	6.1 x 10^7	884	-52	—	+ 900(3)	37	-93	83	+12	+1[illegible]	7
5. γ, Air 100 hrs., 70 F	8	4.1 x 10^7	1063	-42	1116(4)	+367	93(4)	-83	80	+ 9	+ 5	5
6. γ + UV, Air(2) 100 hrs., 250 F	9	3.8 x 10^7	940	-48	—	+642(3)	53	-90	80	+ 9	+24	6
7. γ, Air 16 hrs., 70 F	3A	5.7 x 10^6	2271	+24	449	+ 88	317	-39	71	Nil	+12	1

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Two specimens had an ultimate elongation equal to 100 p[illegible]

Table B-19 (Concluded)

__Time effect__: The effect of time was to increase the amount of cross-linking caused by the initial exposures. Even though 16 hours gamma + vacuum (Condition 1) shows a slight hardness drop, the reaction at all times was predominantly cross-linking.

__Atmosphere effect__: The changes caused by sixteen hours exposure in vacuo were somewhat greater for the same period in air (Condition 1 vs. 7). By 100 hours exposure (Condition 2 vs. 5), the situation was reversed and markedly so. At the elevated temperature of the combined irradiation (Condition 4 vs. 6), the vacuo exposure caused greater change than air exposure. Most of the specimens gained weight. The gain in weight was greater in air than in vacuo and was decreased by the addition of the combined irradiation.

__Type irradiation effect__: Combined irradiation caused more cross-linking in all properties examined (Condition 1 vs. 3, 2 vs. 4 and 5 vs. 6) than equivalent exposure time in straight gamma.

__Observations__: Condition 4, moderate discoloration on face toward ultraviolet lamp. Condition 5, slight discoloration of specimens. Condition 6, slight discoloration of specimens.

Table B-30. PHYSICAL PR(?ERTIES OF COMPOUND 159-62[47]

Base Elastomer - Polychloroprene   Type - Neoprene WRT

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	2654		496		387		74			
1.												
2.												
3. γ + UV, Vac.(2) 16 hrs., 190 F	12	6.4×10^6	1406	-47	—	+ 155(3)	93	-76	80	+ 6	+15	2
4. γ + UV, Vac.(2) 100 hrs., 250 F	10	6.1×10^7	2131	-20	—	+1768(3)	23	-94	94	+20	+ 2	5
5. γ, Air 100 hrs., 70 F	8	4.1×10^7	698	-66	—	+ 570(3)	27	-93	91	+17	+71	4
6. γ + UV, Air(2) 100 hrs., 250 F	9	3.8×10^7	1811	-32	—	+ 540(3)	57	-85	90	+16	+36	3
7. γ, Air 16 hrs., 70 F	3A	5.7×10^6	3055	+15	882	+ 78	250	-35	75	+ 1	+2,	1

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

Table B-30. (Concluded)

<u>Time effect</u>: Increase of exposure markedly increased the effect of cross-linking for all conditious checked (7 vs. 5 and 3 vs. 4).

<u>Atmosphere effect</u>: Air exposure at elevated temperature had less effect on all properties (except tensile) checked (Condition 4 vs. 6). All specimens gained weight, more in air than in vacuo, and the effect of the combined radiation was to lessen the weight gain.

<u>Type irradiation effect</u>: Combined radiation in air (Condition 6) produced less cross-linking than straight gamma radiation for the same condition.

<u>Observations</u>: Condition 3, slight purplish discoloration on face toward UV lamp. Condition 4, purplish discoloration on face toward UV lamp. Condition 5, slight discoloration of specimens, whitish discoloration of protected ends of tabs. Condition 6, brownish discoloration on face toward UV lamp. Condition 7, slight discoloration of specimens.

Table B-31. PHYSICAL PROPERTIES OF COMPOUND 16[illegible]-62 INDUCED BY EXPOSURE TO THE DIFFERENT IRRADIATION CONDITIONS[47]

Base Elastomer - Polychloroprene, Type - Neoprene WRT

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	300 % Modulus psi	300 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg	Rating
As-cured		0	1651		378		437		72			
1. γ, Vac. 16 hrs., 70 F	13	6.4×10^6	3176	+92	723	+ 91	277	-37	77	+ 5	+ 8	1
2. γ, Vac. 100 hrs., 70 F	14	6.1×10^7	1864	+13	—	+ 949(3)	47	-89	91	+19	+20	4
3. γ + UV, Vac.(2) 16 hrs., 95 F	15	5.7×10^6	1991	+21	1800	+ 376	110	-74	80	+ 8	+ 2	2
4. γ, Vac.(4) 100 hrs., 70 F	16	5.0×10^7	1812	+ 9.7	—	+ 615(3)	67	-85	91	+19	+18	3
5. γ, Air 100 hrs., 70 F	17	6.1×10^7	2116	+28	—	+ 956(3)	53	-91	90	+18	+24	5
6. γ + UV, Air(2) 100 hrs., 200 F	18	5.0×10^7	1950	+18	—	+1810(3)	27	-94	92	+20	+14	6

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Table B-31. (Concluded)

<u>Time effect</u>: Cross-linking as evidenced by increase in modulus and hardness and decrease in elongation was initially marked and increased greatly with time (Condition 1 vs. 2).

<u>Atmosphere effect</u>: There were slightly larger increases in air radiation as compared to to vacuo radiation in all properties except hardness (Condition 2 vs. 5). Weight increases were greater in air than in vacuo, and the addition of UV radiation decreased the weight gains.

<u>Type irradiation effect</u>: The combined radiation reduced markedly the amount of cross-linking as compared to that produced by straight gamma radiation (Conditions 1 vs. 3 and 5 vs. 6).

<u>Observations</u>: Condition 3, smoky brown discoloration on face toward UV lamp. Condition 6, purplish discoloration on both faces of specimens.

Table B-32. EFFECTS OF VACUUM AND OF VACUUM WITH ULTRAVIOLET RADIATION ON ELASTOMERS*(46)

Material	Type of Exposure**	Temperature (F)	Exposure Time (hour)	Weight Change (per cent)	Tensile Strength: Before Exposure (psi)	Tensile Strength: After Exposure (psi)	Tensile Strength: Change (per cent)	Breaking Elongation: Before Exposure (in./in.)	Breaking Elongation: After Exposure (in./in.)	Breaking Elongation: Change (per cent)
Neoprene	Vacuum	80	24	+ 0.04	2288	2378	+ 3.9	0.515	0.525	+ 1.9
	Vacuum	80	96	- 0.14	2288	2306	+ 0.8	0.515	0.532	+ 3.3
	Vacuum	[illegible]	312	- 0.93	2288	2286	- 0.1	0.515	0.518	- [illegible].6
	Vacuum and ultraviolet	155	24	- 3.27	2288	2658	+ 16.2	0.515	[illegible]	- 16.9
	Vacuum and ultraviolet	155	96	- 5.93	2288	2566	+ 12.2	0.515	0.302	- 41.3
	Vacuum and ultraviolet	155	312	- 5.95	2288	2858	+ 25.0	0.515	[illegible]	- 35.0

* Values are averages of two specimens.

** Maximum vacuum pressure: on the order of 1×10^{-5} mm Hg.

Table B-33. EXPOSURE OF NEC PRENE VULCA IZATES TO HIGH VACUUM AT VARIOUS TEMPE TURE (45)

Property Measured	Original	Exposed to Vacuum of 10^{-5} mm Hg for 56 Days at Room Temperature	1 F: Vacuum of 6 x 10^{-5} mm Hg for 7 Days	1 F: Air Oven for 7 Days	212 F: Vacuum of 7.8 x 10^{-6} mm Hg for 5 Days	212 F: Air Oven for 5 Days	300 F: Vacuum of 2 x 10^{-6} mm Hg for 5 Days	300 F: Air Oven for 5 Days
Unplasticized Compound (M72)								
Tensile strength, psi	2490	2180	2170	2300	2460	2500	1860	--
Modulus, psi at 300 per cent elongation	2010	1950	2110	2030	2300	2060	—	—
Elongation, per cent	350	330	315	325	310	340	210	—
Hardness, Shore A	62	61	63	63	59	61	70	—
Strain, per cent elongation at 400 psi	119	122	123	113	109	94	70	—
Low temperature flexibility, ASTM D1043, T200, F	-27	-28	-29	-28	-28	--	-27	—
Weight change, per cent	—	+0.2	-0.9	—	-2.1	-1.0	-4.3	-14.7

Table B-33. (Concluded)

Property Measured	Original	Exposed to Vacuum of 10^{-5} mm Hg for 56 Days at Room Temperature	158 F		212 F		300 F	
			Vacuum of 8×10^{-5} mm Hg for 7 Days	Air Oven for 7 Days	Vacuum of 7.8×10^{-6} mm Hg for 5 Days	Air Oven for 5 Days	Vacuum of 2×10^{-6} mm Hg for 5 Days	Air Oven for 5 Days
				Plasticized Compound (M72B)				
Tensile strength, psi	2010	2070	2110	2050	2120	2170	1660	Too brittle to test
Modulus, psi at 300 per cent elongation	1100	1180	1220	1250	1710	1310	—	Too brittle to test
Elongation, per cent	380	375	340	340	330	380	220	Too brittle to test
Hardness, Shore A	52	54	59	55	60	50	63	Too brittle to test
Strain, per cent elongation at 400 psi	173	180	160	187	137	116	100	Too brittle to test
Low temperature flexibility, ASTM D1043, T_{200}, F	-54	-44	-33	-54	—	—	-30	Too brittle to test
Weight change, per cent	—	-4.7	-9.5	—	-8.0	-2.2	-8.8	-18.6

Table B-34. EXPOSURE OF SBR VULCANIZATES TO HIGH VACUUM AT VARIOUS TEMPERATURES[45]

Property Measured	Original	Exposed to Vacuum of 10^{-5} mm Hg for 56 Days at Room Temperature	Vacuum of 8×10^{-5} mm Hg for 7 Days	Air Oven for 7 Days	Vacuum of 7.8×10^{-6} mm Hg for 5 Days	Air Oven for 5 Days	Vacuum of 2.1×10^{-6} mm Hg for 5 Days	Air Oven for 5 Days
			Compound Containing No Antiozonant (S119)(1)					
Tensile Strength, psi	3590	3440	3180	343	3450	2980	2570	--
Modulus, psi at 300% E	1650	1780	2220	2040	--	--	--	--
Elongation, percent	530	490	380	430	320	390	220	--
Hardness, Shore A	67	67	70	70	73	74	75	--
Strain, percent E at 400 psi	120	116	92	-	169	154	65	--
Low Temperature Flexibility, ASTM D1043, T_{200}, F	-42	-41	-42	-38	--	--	-38	--
Ozone Resistance, time to first crack, 50 pphm, loop specimen	2 hrs	2 hrs	2 hrs	2 hrs	2 hrs	2 hrs	2 hrs	--
Weight Change, percent	--	-0.3	-1.4	--	-1.4	-1.1	-3.1	-1.4
			Compound Containing Antiozonant (S119B)(1)					
Tensile Strength, psi	3240	3040	3250	3310	3690	3370	2900	Too brittle to test
Modulus, psi at 300% E	1220	1380	1930	1650	--	2600	--	Too brittle to test
Elongation, percent	605	540	480	540	410	400	260	Too brittle to test
Hardness, Shore A	65	66	68	68	62	75	76	Too brittle to test
Strain, percent E at 400 psi	141	148	122	--	92	89	66	Too brittle to test
Low Temperature Flexibility, ASTM D1043, T_{200}, F	-41	-39	-39	-37	--	--	-36	Too brittle to test
Ozone Resistance, time to first crack, 50 pphm, loop specimen	No cracks 90 days	2 hrs	1 day	1 day	2 hrs	2 hrs	2 hrs	Too brittle to test
Weight Change, percent	--	-0.9	-2.6	--	-2.8	-1.1	-4.2	-2.1

(1) See Table A-1 for formulation.

Table B-35. CURE SCHEDULES OF THE POLYSULFIDES USED IN THE IRRADIATION STUDIES[47]

Compound	Curing Data	Recipe, Parts	
		Base Compound	Accelerator
146-62	MnO_2 Cured	100	10
154-62	Dichromate Cured	7.5	1.0
155-62	Pb-peroxide Cured	100	10
167-62	MnO_2 Cured	100	10

All compounds above were cured at room temperature for at least one week before exposure.

Table B-36. PHYSICAL PROPERTIES OF COMPOUND 146-62[47]

Base Elastomer - Polysulfide, Type MnO_2 Cured

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	449		229		377		62			
2. γ, Vac. 100 hrs., 70 F	4	4.9×10^7	352	-22	191	- 33	287	-24	59	- 3	-40	4
3. γ + UV, Vac.(2) 16 hrs., 190 F	12	6.4×10^6	350	-22	191	- 17	420	+11	61	- 1	-22	2
4. γ + UV, Vac.(2) 100 hrs., 250 F	10	6.1×10^7	241	-46	—	+163(3)	40	-89	64	+ 2	-80	6
5. γ, Air 100 hrs., 70 F	8	4.1×10^7	[illegible]	-24	198	- 14	283	-25	59	- 3	- 6	3
6. γ + UV, Air(2) 100 hrs., 250 F	9	[illegible] $\times 10^7$	295	-34	287	+ 25	130	-66	[illegible]	+ 2	-70	5
7. γ, Air 16 hrs., 70 F	3A	[illegible] $\times 10^6$	378	-15	222	- 3.0	443	+17	64	+ 2	- 3	1

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

Table B-36. (Concluded)

<u>Time effect</u>: In combined radiation in vacuum, the tensile strength was not affected greatly by time. The 100 per cent modulus increased markedly, hardness increased slightly, and the ultimate elongation dropped markedly as exposure time increased. In straight gamma in air, the four physical properties did not vary significantly as exposure time increased.

<u>Atmosphere effect</u>: The compound apparently reacted about the same in vacuum and in air. All specimens lost weight, markedly so in the case of combined radiation.

<u>Type irradiation effect</u>: The combined radiation at 100 hours in air and vacuum showed cross-linking and the straight gamma radiation at 100 hours in air and vacuum showed scission.

<u>Observations</u>: Condition 2, slight darkening (brown cast). Condition 3, moderate darkening on face toward UV lamp—slight on back face. Condition 4, heavy blackening on face toward UV lamp—moderate on other face. Condition 5, moderate discoloration, (brown) occlusion in break. Condition 6, specimens were more heavily blackened on one end indicating uneven exposure—slight to moderate darkening on back faces. Condition 7, slight darkening (brown cast) soot on specimens.

Table B-37. PHYSICAL PROPERTIES OF COMPOUND 154-62[47]

Base Elastomer - Polysulfide, Type - Dichromate Cured

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	387		329		160		74			
1. γ, Vac. 16 hrs., 70 F	13	6.4×10^6	469	-21	397	+ 21	163	+ 1.9	73	- 1	-13	4(5)
2. γ, Vac. 100 hrs., 70 F	14	6.1×10^7	419	+ 8.3	363	+ 10	153	- 4.4	72	- 2	-18	1(5)
3. γ + UV, Vac.(2) 10 hrs., 95 F	15	5.7×10^6	155	-60	—	+ 57(3)	30	-81	65	- 9	-27	5
4. γ, Vac.(4) 100 hrs., 70 F	16	5.0×10^7	399	+ 3.1	354	+ 7.6	130	-19	72	- 2	- 2	2
5. γ, Air 100 hrs., 70 F	17	6.1×10^7	423	- 9.3	377	+ 15	143	-10	70	- 4	-15	3
6. γ + UV, Air(2) 100 hrs., 200 F	18	5.0×10^7	167	-56	—	+ 54(3)	33	-79	60	-14	-25	5

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

(5) The reasons for the apparently reversed ratings are discussed in the st section of Part C, Phase III, Reference 47.

Table B-37 (Concluded)

Time effect: In vacuum and straight gamma radiation the physical properties were not markedly affected by time with the exception of the tensile strength which was affected to some degree. The initial increase in modulus, followed by decreasing values (from the initial increase), would indicate an initial period of cross-linking, followed by predominant scission

Atmosphere effect: There was slightly greater reaction caused by radiation in air than in vacuo. All specimens lost weight and the weight loss was greater in the case of combined scission.

Type irradiation effect: All four physical properties are markedly affected. The observations made in the case of irradiation Condition 6 could explain the sharp decrease of elongation and sharp increase of 100 per cent modulus as follows: the compound was probably decomposed by the high temperature giving gas formation and charring which rendered the specimen weak. Irradiation effects of most conditions indicated scission.

Observations: Condition 3, marked darkening on both faces. Condition 6, heavy blackening on face toward UV lamp. Moderate discoloration on other face. Some swelling on face toward UV lamp. Hardness 55 on one end and 65 on the other end of specimens.

Table B-38. PHYSICAL PROPERTIES OF COMPOUND 155-62[47]

Base Elastomer - Polysulfide, Type - Lead Peroxide Cured

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	412		108		520		55			
1. γ, Vac. 16 hrs, 70 F	13	6.4×10^6	314	-24	133	- 21	510	- 1.9	52	- 3	- 9	1
2. γ, Vac. 100 hrs., 70 F	14	6.1×10^7	298	-28	131	+ 22	363	-30	52	- 3	- 5	3
3. γ + UV, Vac.(2) 16 hrs., 95 F	15	5.7×10^6	101	-76	—	+501(3)	10	-98	52	- 3	-159	4
4. γ, Vac.(4) 100 hrs., 70 F	16	5.0×10^7	302	-27	154	- 8.2	310	-40	55	Nil	- 11	2
5. γ, Air 100 hrs., 70 F	17	5.1×10^7	291	-29	155	- 7.7	303	-42	54	- 1	- 3	3
6. γ + UV, Air(2) 100 hrs., 200 F	18	5.0×10^7	—	—	—	—	—	—	—	—	—	5

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Table B-38. (Concluded)

Time effect: In Conditions 1 and 2 the over-all physical properties were not affected greatly by time. Both conditions indicated scission.

Atmosphere effect: Straight gamma radiation 100 hours showed no appreciable changes in physical properties. All specimens lost weight and in the one case of combined radiation where the specimens were weighable, the loss was quite marked.

Type irradiation effect: The combined radiations, with elevated temperatures, weakened the compound which apparently underwent scission. Straight gamma also showed scission but no temperature effect.

Observations: Condition 1, slight greying on specimens. Less residual "set" after tensile test than unaged. Condition 2, moderate greying of specimens. Still less residual set after tensile test. Condition 3, specimens blackened and shriveled. Condition 4, bleaching of specimens. Condition 5, specimens markedly "greyed". Condition 6, specimens decomposed and charred.

Table B-39. PHYSICAL PROPERTIES OF COMPOUND 167-62[47]

Base Elastomer - Polysulfide, Type - MnO_2 Cured

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	479		184		483		59			
1. γ, Vac. 16 hrs., 70 F	13	6.4×10^6	453	- 3.3	200	+ 8.9	490	+ 1.5	57	-2	- 6	1
2. γ, Vac. 100 hrs., 70 F	14	6.1×10^7	406	-15	148	- 29	520	+ 7.7	54	-5	- 5	2
3. γ + UV, Vac.(2) 16 hrs., 95 F	15	2.7×10^6	335	-30	153	- 17	365	-25	58	-1	-15	5
4. γ, Vac.(4) 100 hrs., 70 F	16	5.0×10^7	360	-25	142	- 23	493	+ 2.1	54	-5	-22	3
5. γ, Air 100 hrs., 70 F	17	6.1×10^7	409	-15	145	- 22	583	+21	55	-4	- 1	4
6. γ + UV, Air 100 hrs., 200 F	18	5.0×10^7	153	-68	—	+748(3)	10	-99	60	+1	-86	6

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Table B-39. (Concluded)

<u>Time effect</u>: Time in Conditions 1 and 2 did not affect appreciably the physical properties.

<u>Atmosphere effect</u>: Conditions 2 and 5 showed no marked change in physical properties. All specimens lost weight, more so in the case of the combined radiations.

<u>Type irradiation effect</u>: Conditions 5 and 6 underwent scission, but apparently the data for Condition 6 were mainly affected by the high temperature. Conditions 3 and 1 indicated scission and combined radiation, with the high temperature. Conditions 3 and 1 indicated scission and combined radiation, with the help of a high temperature, weakened the compound even further as indicated by a marked decrease of the tensile strength, 100 per cent modulus, and elongation.

<u>Observations</u>: Condition 2, specimens bonded to case and to one another. Condition 3, smoky brown discoloration on face of specimen. Condition 6, surface browning and hardening, large amount of blistering on two specimens.

TABLE B-40. ELASTOMERS - TENSILE PROPERTIES[a] OF THIOKOL ST VERSUS POSTIRRADIATION STORAGE TIME[48]

Integrated Neutron Flux (N), n cm^{-2}[b] (E > 2.9 Mev)[b] Gamma Exposure (G), ergs g^{-1} (C)[b]	Days Tested After Irradiation	Modulus[c], psi At 25% Elongation	Modulus[c], psi At 50% Elongation	Modulus[c], psi At 100% Elongation	Ultimate[c], psi	Ultimate Elongation[c], %
Control	1	131/15 /4	193/10 /7	334/ 5.8/7	[illegible]42/6.2/7	281/ 6.6/7
	3	144/ 7.5/8	204/ 6.5/8	339/ 5.3/8	916/2.4/8	275/ 5.7/8
	10	132/ 4.9/9	183/ 7.8/9	314/ 1.7/9	800/7.3/9	313/21 /9
	34	141/ 7 /10	210/ /10	315/ 5.4/10	825/9.3/10	265/13 /10
N 1.5×10^{15} G 1.1×10^{10}						
	1	95/12 /5	157/12 /5	346/ 6.6/5	472/8.6/5	138/ 7.[illegible]/5
	3	120/14 /5	186/18 /5	353/ 9.4/5	498/3.6/5	146/11 /5
	10	143/ 7.9/5	245/ 8.3/5	391/ 3.3/5	508/1.3/5	128/13 /5
	34	147/ 7.2/5	231/ 9.8/5	439/11 /5	624/6.1/5	138/ 7.7/5

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Irradiation and storage temperature 75 F.

(c) Test temperature 75 F.

TABLE B-41. ELASTOMERS - TENSILE PROPERTIES[a] OF PU 3109B AND PU 6865 VERSUS POSTIRRADIATION STORAGE TIME[48]

Integrated Neutron Flux (N), n cm^{-2} (E > 2.9 Mev)[b] Gamma Exposure (G), ergs g^{-1} (C)[b]	Days Tested After Irradiation	Modulus[c], psi At 25% Elongation	At 50% Elongation	At 100% Elongation	Ultimate[c], psi	Ultimate Elongation[c], %
		PU-3109B				
Control	1	890/10 /4	1107/5.4/4	1414/12 /4	4296/3.9/4	460/11 /4
	3	944/2.8/8	1199/2.8/8	1550/1.7/8	4276/6.8/8	463/1.8/8
	10	1013/4.5/7	1278/4.5/7	1625/4.3/7	5016/13 /7	450/8.2/7
	34	983/4.4/8	1200/5.4/8	1459/7 /8	4745/12 /8	434/6.4/8
N 4.7 x 10^{15} G 2.10 x 10^{10}						
	2	1220/12 /5	1598/3.4/5	2624/9.6/5	3221/4.9/5	145/21 /5
	3	1409/11 /5	1957/4.1/5	2910/6.3/5	3390/12 /5	125/19 /5
	10	1775/4.2/5	2415/11 /5	3344/24 /5	3529/13 /5	106/59 /5
	34	1300/6.1/5	1870/4 /5	2823/3.8/5	3325/2.8/5	123/9.5/5
		PU 6865				
Control	1	229/15 /8	358/5.7/8	708/2.9/8	7739/8.5/8	696/5.7/8
	3	267/8.6/6	434/5.3/6	754/6 /6	7365/7.1/6	669/3.4/6
	10	270/13 /7	470/4.6/7	762/2.9/7	6955/12 /7	666/3.8/7
	34	253/25 /7	409/13 /7	638/3.4/7	7222/5.3/7	
N 3.4 x 10^{15} G 2.2 x 10^{10}						
	1	309/16 /5	744/25 /5		922/18 /5	59/26 /5
	3	343/5.2/3	858/12 /3		963/8.8/3	58/26 /3
	10	315/8 /5	759/14 /5		973/10 /5	57/5.7/5
	34	320/27 /5	756/13 /5		899/	56/18 /5

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Irradiation and storage temperature 75 F.

(c) Test temperature 75 F.

TABLE B-42. ELASTOMERS - TENSILE PROPERTIES[a] OF PU-GENTHANE-S VERSUS POSTIRRADIATION STORAGE TIME[48]

Integrated Neutron Flux (N) n cm^{-2} (E > 2.9 Mev)[b] Gamma Exposure (G), ergs g^{-1} (C)[b]	Days Tested After Irradiation	Modulus[c], psi			Ultimate[c], psi	Ultimate Elongation[c], %
		At 25% Elongation	At 50% Elongation	At 100% Elongation		
Control	1	108/ /3	163/ /3	345/5.6/8	2499/15 /8	457/8.7/8
	3	106/3.9/5	148/8.2/5	309/11 /5	2476/11 /5	486/6.7/5
	10	98/12 /7	147/11 /7	297/12 /7	2463/9.1/7	490/9.1/7
	34	101/9.5/8	151/7.9/8	298/6.4/8	2360/4 /8	468/3.6/8
N 5.7 x 10^{15} G 3.7 x 10^{10}						
	1	136/36 /2	380/38 /2		495/8 /4	55/28 /4
	3	92/38 /5	246/26 /5		432/16 /5	61/9.3/5
	10	116/14 /5	287/15 /5		463/18 /5	69/12 /5
	34	88/30 /4	264/5 /4		386/13 /4	63/12 /4

(a) Data are given as $\overline{x}$/S.D./n, where $\overline{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\overline{x}$ and S.D.

(b) Irradiation and storage temperature 75 F.

(c) Test temperature 75 F.

TABLE B-43. ELASTOMERS - TENSILE PROPERTIES[a] OF PU-4250 VERSUS POSTIRRADIATION STORAGE TIME[48]

Integrated Neutron Flux (N), n cm^{-2} (E > 2.9 Mev)[b] Gamma Exposure (G), ergs g^{-1} (C)[b]	Days Tested After Irradiation	Modulus[c], psi At 25% Elongation	Modulus[c], psi At 50% Elongation	Modulus[c], psi At 100% Elongation	Ultimate[c], psi	Ultimate Elongation[c], %
Control	1	1184/3.1/5	1397/3.6/5	1835/2.7/5	5251/5.5/5	583/6.8/5
	3	1219/1.5/5	1536/3.6/5	1945/3.8/5	4657/5.4/5	478/3.4/5
	10	1125/9.1/8	1479/4.1/8	1922/1.6/8	4575/3.6/8	549/2.8/8
	34	1088/17 /8	1450/4.1/8	1775/3.5/8	4688/10 /8	583/4.7/8
N 3.4×10^{15} G 2.2×10^{10}						
	1	1241/3 /5	1904/11 /5		2689/1.9/5	84/22 /5
	3	1466/8.3/5	2233/8.3/5		2814/8.4/5	77/25 /5
	10	1226/7.4/5	2227/6.7/5		2764/5.9/5	79/21 /5
	34	1489/14 /5	2066/13 /5		2574/3.9/5	77/14 /5

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Irradiation and storage temperature 75 F.

(c) Test temperature 75 F.

TABLE B-44. POLYURETHANE RUBBERS - TENSILE PROPERTIES[a] OF DUPONT ADIPRENE L VERSUS TEMPERATURE AND IRRADIATION[48]

Integrated Neutron Flux (N), n cm^{-2} (E > 2.9 Mev) Gamma Exposure (G), ergs g^{-1} (C)[b]	Irradiation Temp, F	Modulus[b], psi At 100% Elongation	At 200% Elongation	Ultimate[b], psi	Ultimate Elongation[b], %
Control	80	970/4.3/10	1416/3.1/10	4065/8.4/10	433/13 /10
N 2.5×10^{13} G 5.2×10^{7}	175	1030/1.3/5	1460/2.4/5	4251/23 /5	404/2.2/5
N 2.9×10^{13} G 6×10^{7}	75	1013/2 /5	1432/5.1/3	4869/6.8/3	420/4.6/4
N 3.9×10^{13} G 6.5×10^{7}	-45	1028/2.6/5	1432/1.5/5	4661/8.9/4	433/4.5/4
N 1×10^{16} G 1.4×10^{10}	75			1562/6.3/4	142/6.9/4
Control	80 260	1282/1.7/10 1182/1.5/10	1798/2.8/10 1623/1.8/10	5346/6.3/9 5542/8.1/10	390/1.7/9 420/3.1/10
N 1.2×10^{15} G 2×10^{9}	80	1263/4.3/5	1831/2.5/5	5055/10 /3	393/8.2/5
N 1.8×10^{15} G 5.4×10^{9}	260	921/5.7/4	1214/4 /4	1513/1.6/5	299/8.6/5
N 4.5×10^{16} G 7×10^{10}	80			1679/21 /5	75/26 /5

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

(b) Test temperature 80 F.

TABLE B-45. POLYURETHANE RUBBERS - TENSILE PROPERTIES(a) OF DUPONT L-167 VERSUS TEMPERATURE AND IRRADIATION(48)

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation Temp, F	DuPont L-167(a)(b) Modulus, psi At 100% Elongation	DuPont L-167(a)(b) Modulus, psi At 200% Elongation	DuPont L-167(a)(b) Ultimate, psi	DuPont L-167(a)(b) Ultimate Elongation, %	DuPont L-167(b)(b) Modulus, psi At 100% Elongation	DuPont L-167(b)(b) Modulus, psi At 200% Elongation	DuPont L-167(b)(b) Ultimate, psi	DuPont L-167(b)(b) Ultimate Elongation, %
Control	80	1777/2.9/10	2514/2.6/10	5414/7.5/10	348/4.8/9	233/6.2/8	300/7.4/9	1825/12 /7	584/4.4/7
N 2.5 x 10^{13} G 5.2 x 10^{7}	175	1713/4.6/5	2534/2.3/5	6492/10 /5	360/3.6/5	248/15 /3	348/15 /3	1896/23 /3	550/14 /3
N 2.9 x 10^{13} G 6 x 10^{7}	75	1685/[illegible].7/5	2560/1.8/5	6433/3.2/5	336/2.6/5	231/1.9/4	312/7.2/4	2864/65 /4	527/7.9/3
N 3.9 x 10^{13} G 6.5 x 10^{7}	-45	1793/5.5/5	2680/4.9/5	5668/14 /5	366/5.9/5	257/28 /5	284/22 /3	1140/39 /4	527/7.9/3
N 1 x 10^{16} G 1.4 x 10^{10}	75	2064/4.4/4		3301/16 /4	217/8.2/3	120/1.2/4	196/15 /4	579/18 /5	383/14 /3
Control	80 260	2085/1.5/10 2060/2.3/10	3014/3 /9 2903/2.2/10	5949/8.3/9 6013/11 /10	328/4.1/9 358/5 /10	252/10 /10 219/8.5/10	343/11 /10 303/8.9/10	1002/[illegible] /7 1361/13 /10	4[illegible]/7.4/7 499/[illegible].2/10
N 1.2 x 10^{15} G 2 x 10^{9}	80	2131/0.[illegible]/5	3197/1.6/5	4857/9.3/5	290/8 /5	213/4 /5	305/12 /5	1899/7 /4	480/6.6/4
N 1.8 x 10^{15} G 5.4 x 10^{9}	260	1766/7.1/5	2160/2.5/5	3111/3.4/5	326/6.3/5	120/6.4/5	173/9.7/5	575/16 /4	465/2.6/4
N 4.5 x 10^{16} G 7 x 10^{10}	80			2650/6.3/4	63/7.6/4			604/9.4/5	69/9.4/[illegible]

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual [illegible]ation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

TABLE B-46. POLYURETHANE RUBBERS - TENSILE PROPERTIES(a) OF DISOGRIN 3DSA 8050 AND 3DSA 9045 VERSUS TEMPERATURE AND IRRADIATION (18)

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev) Gamma Exposure (G) ergs g^{-1} (C)	Irradiation Temp, F	Disogrin 3DSA 8050(b) Modulus, psi At 100% Elongation	Disogrin 3DSA 8050(b) Modulus, psi At 200% Elongation	Disogrin 3DSA 8050(b) Ultimate, psi	Disogrin 3DSA 8050(b) Ultimate Elongation, %	Disogrin 3DSA 9045(b) Modulus, psi At 100% Elongation	Disogrin 3DSA 9045(b) Modulus, psi At 200% Elongation	Disogrin 3DSA 9045(b) Ultimate, psi	Disogrin 3DSA 9045(b) Ultimate Elongation, %
Control	80	625/4.9/9	876/6.1/8	5759/7.4/10	588/3.3/10	1446/3.8/9	1790/4.2/8	3597/15 /10	6 3/9.2/8
N 2.5 x 10^{13} G 5.2 x 10^{7}	175	602/6.3/5	852/5.4/5	5129/10 /5	652/3.3/5	1475/4.3/5	1834/4.2/4	3384/8.2/5	678/5.7/5
N 2.9 x 10^{13} G 6 x 10^{7}	75	629/4.3/4	888/4.1/4	5703/3.8/4	580/6.1/3	1838/13 /5	2058/8.7/5	4058/12 /5	632/2.7/5
N 3.9 x 10^{13} G 6.5 x 10^{7}	-45	573/4.1/5	822/1.3/4	5822/6.3/5	614/2.1/5	1398/3.1/5	1832/2.7/5	3672/7.7/5	632/2.7/5
N 1 x 10^{16} G 1.4 x 10^{10}	75	719/8.6/4	1094/9.9/4	2088/10 /4	333/12 /4	1454/8 /5		1596/7.7/5	130/9.9/5
Control	80 260	632/2.5/10 621/3.9/10	890/2.2/10 862/5.1/10			1504/2.2/10 1344/2.8/10	1903/3.8/10 1703/3.8/10	3407/7.2/10 2928/6.7/10	598/6.5/10 616/3.4/10
N 5.3 x 10^{15} G 1.3 x 10^{10}	-65	641/2.4/5	836/2.2/4	2861/11 /3	682/2.2/3	1416/5.3/2	1565/ /1	1541/6.9/5	293/31 /4
N 3.7 x 10^{15} G 1.5 x 10^{10}	80	72 /3.3/5	1130/2.2/5	2537/4.9/4	375/1.3/4	1529/7.2/5	1698/6.2/5	1929/5.8/3	348/4.2/3
N 3.5 x 10^{15} G 1.9 x 10^{10}	260					14[illegible]/13 /5	1688/4.7/3	2071/15 /4	313/3.8/3
N 4.5 x 10^{16} G 7 x 10^{10}	80			1075/12 /5	[illegible]/15 /5			[illegible]472/11 /4	49/20 /4

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

TABLE B-47. POLYURETHANE RUBBERS - TENSILE PROPERTIES[a] OF DISOGRIN 2DSA 8445 AND 2DSA 9840 VERSUS TEMPERATURE AND IRRADI[illegible] (48)

Integrated Neutron Flux (N) n cm^{-2} (E > 0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation Temp, F	Disogrin 2DSA 8445[b] Modulus, psi At 100% Elongation	Disogrin 2DSA 8445[b] Modulus, psi At 200% Elongation	Disogrin 2DSA 8445[b] Ultimate, psi	Disogrin 2DSA 8445[b] Ultimate Elongation, %	Disogrin 2DSA 9840[b] Modulus, psi At 100% Elongation	Disogrin 2DSA 9840[b] Modulus, psi At 200% Elongation	Disogrin 2DSA 9840[b] Ultimate, psi	Disogrin 2DSA 9840[b] Ultimate Elongation, %
Control	80	604/2.1/10	844/3.2/10	5418/2.8/10	586/3.5/9	1494/8.3/10	1876/7.2/10	5477/9 /10	562/7.8/10
N 2.5 x 10^{13} G 5.2 x 10^{7}	175	576/2.8/5	852/3.8/5	5505/7.5/4	565/3.4/5	1415/7.1/5	1788/6.9/5	5489/5.1/5	542/6.4/5
N 2.9 x 10^{13} G 6 x 10^{7}	75	625/3 /5	862/3.9/5	5571/6.3/5	562/6.1/5	1493/8.4/5	1842/8.6/5	5751/12 /5	568/8.6/4
N 3.9 x 10^{13} G 6.5 x 10^{7}	-45	534/3.1/5	836/2.3/5	5198/3.8/5	564/5.3/5	1466/8.2/5	1794/9.6/5	5632/13/5	574/3.7/5
N 1 [illegible] 10^{13} G 1.4 x 10^{10}	75	808/5 /4	852/25 /3	1951/8.3/4	341/2.9/4	1637/7.6/5	1904/7.4/5	3214/18 /5	394/9.8/5
Control	80	952/4.2/10	915/3.8/10		645/3.7/7	1558/5.1/10	1905/3.4/10	5661/15 /9	563/4.2/9
	260	569/1.4/10	786/3.3/10	5082/ /1	555/ /1	1535/5.1/10	1898/4.8/9	5917/7.3/10	599/6.5/9
N 5.3 x 10^{15} G 1.3 x 10^{10}	-65	655/8.3/5	832/8 /5	2907/9.3/5	672/7.7/5	1509/13 /5	1728/15 /5	3205/17 /5	616/[illegible].7/5
N 6.7 x 10^{15} G 1.5 x 10^{10}	80	745/4.5/4	1093/3 /4	2625/22 /5	377/8.6/5	1859/3.7/4	2212/4.5/4	3418/11 /5	346/7.5/5
N 8.5 x 10^{15} G 1.9 x 10^{10}	260					1627/[illegible] /5		2524/17 /4	330/14 /5
N 4.5 x 10^{16} G 7 x 10^{10}	80			1050/35 /5	[illegible] /5			2585/12 /5	56/7.7/5

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

TABLE B-48. POLYURETHANE RUBBERS - TENSILE PROPERTIES[a] OF DISOGRIN IDSA 7560 AND IDSA 9250 VERSUS TEMPERATURE AND IRR[illegible]ION[18]

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation Temp, F	Disogrin IDSA 7560[b] Modulus, psi At 100% Elongation	Disogrin IDSA 7560[b] Modulus, psi At 200% Elongation	Disogrin IDSA 7560[b] Ultimate, psi	Disogrin IDSA 7560[b] Ultimate Elongation, %	Disogrin IDSA 9250[b] Modulus, psi At 100% Elongation	Disogrin IDSA 9250[b] Modulus, psi At 200% Elongation	Disogrin IDSA 9250[b] Ultimate, psi	Disogrin IDSA 9250[b] Ultimate Elongation, %
Control	80	548/3.1/9	826/12 /[illegible]	4749/8.5/9	699/4.3/9	1781/4.3/9	2446/4.4/10	4646/9.1/10	536/8.5/10
N 2.5 x 10^{13} G 5.2 x 10^{7}	175	4[illegible]3/8.6/4	826/6.4/5	4743/9.7/2	715/1.2/2	1735/2.7/5	2408/2.4/5	4691/10 /5	556/15 /5
N 2.9 x 10^{13} G 6 x 10^{7}	75	483/16 /5	820/5.2/5	5292/7.5/2	67[illegible]/ /1	1734/3.5/5	2384/2.6/5	4809/6.9/4	533/4.6/4
N 3.9 x 10^{13} G 6.5 x 10^{7}	-45	546.7.6/5	820/6 /5	4327/20 /5	670/9 /5	1780/4.5/5	2470/26 /5	4621/8.3/5	566/14 /5
N 1 x 10^{15} G 1.4 x 10^{10}	75	745/6.7/5		1133/4.2/5	178/7.3/5	2074/2.4/5		2384/3 /5	178/2.4/5
Control	80 260	523/5.8/10 459/4.5/10	364/6.1/10 776/7.6/10	5254/11 /7	718/3.4/10	1891/3 /10 1804/3 /10	2464/6 /10 2441/2.7/10	5544/13 /10 4585/12 /9	578/3.9/10 566/3.6/9
N 5.3 x 10^{15} G 1.3 x 10^{10}	-65	6[illegible]4/8.2/5	921/6.2/5	2477/9.8/5	677/5.7/5	1745/3 /5	2105/3.8/5	2969/14 /4	503/5.1/5
N 6.7 x 10^{15} G 1.5 x 10^{10}	80	1[illegible]6/17 /2	1415/ /1	1541/13 /5	257/31 /3			2936/7.5/5	164/1.3/5
N 8.5 x 10^{15} G 1.9 x 10^{10}	260	466/5.3/4		1474/15 /4	362/3.4/4	1[illegible]8/4.9/5		2285/5.6/5	247/11 /5
N 4.5 x 10^{16} G 7 x 10^{10}	80			850/12 /5	[illegible]5/18 /5			2426/14 /5	27/32 /5

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

TABLE B-49. POLYURETHANE RUBBERS - TENSILE PROPERTIES(a) OF GENERAL TIRE POLYURETHANE TYPE R AND DISOGRIN IDSA 6865 VERSUS TEMPERATURE AND IRRADIATION(48)

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation Temp, F	General Tire Polyurethane Type R(b) Modulus, psi At 100% Elongation	At 200% Elongation	Ultimate, psi	Ultimate Elongation, %	Disogrin IDSA 6865(b) Modulus, psi At 100% Elongation	At 200% Elongation	Ultimate, psi	Ultimate Elongation, %
Control	80	301/6.6/10	700/9.5/10	3900/15 /10	557/7.6/10	673/5 /10	1134/7.4/10	5198/19 /9	704/2.4/9
N 2.5 x 10^{13} G 5.2 x 10^{7}	175	317/2.9/5	718/6.6/5	3523/6.1/5	522/4.1/5	658/9.9/5	1078/3 4/5	5216/ /1	
N 2.9 x 10^{13} G 6 x 10^{7}	75	338/9.9/5	734/11 /5	3962/6.2/5	582/3.1/5	711/7.7/5	1190/5.2/5	5281/4.2/5	666/3.2/5
N 3.9 x 10^{13} G 6.5 x 10^{7}	-45	319/5.9/5	744/3.2/5	3469/20 /5	528/13 /5	669/4.8/5	1166/9.4/5	5056/15 /5	708/3.4/[illegible]
N 1 x 10^{16} G 1.4 x 10^{10}	75	293/8.2/5	880/6.4/5	1187/10 /5	258/2.4/3	770/7.5/5		[illegible]/11 /5	214/10 /5
Control	80 260	313/6.2/10 242/11 /8	736/3.8/10 727/9.3/10	4102/7 /10 4160/7.9/10	596/4.4/10 609/6.4/10	683/8.7/10 662/5 /10	1115/9.1/10 1090/3.2/10	4989/7 /6 4345/18 /7	685/4.3/6 676/9.6/7
N 5.2 x 10^{15} G 1.3 x 10^{10}	-65	190/5.4/5	462/5.4/5	1741/5.6/5	468/16 /5	773/8.1/5	1132/4.1/5	2696/13 /5	588/8.4/5
N 6.7 x 10^{15} G 1.5 x 10^{10}		472/9.7/5		1265/16 /5	274/3.6/4	1158/7.1/2		1410/4.5/5	140/9.2/5
N 8.5 x 10^{15} G 1.9 x 10^{10}	260	571/8.1/5		992/16 /5	139/17 /5	572/3.7/5	884/3.1/4	1260/6.2/5	278/3.9/5
N 4.5 x 10^{16} G 7 x 10^{10}	80			890/7.8/5	[illegible] 4/5			830/13 /5	36/24 /5

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

(b) Test temperature 80 F.

TABLE B-50. POLYURETHANE RUBBERS - TENSILE PROPERTIES[(a)] OF GENTHANE S-1 AND S-2 VERSUS TEMPERATURE AND IRRADIATION[(48)]

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation Temp, F	Genthane S-1[(b)] Modulus, psi At 100% Elongation	Genthane S-1[(b)] Modulus, psi At 200% Elongation	Genthane S-1[(b)] Ultimate, psi	Genthane S-1[(b)] Ultimate Elongation, %	Genthane S-2[(b)] Modulus, psi At 100% Elongation	Genthane S-2[(b)] Modulus, psi At 200% Elongation	Genthane S-2[(b)] Ultimate, psi	Genthane S-2[(b)] Ultimate Elongation, %
Control	80	329/11 /10	810/6.3/10	5740/4 /10	557/2.9/10	328/17 /10	900/6.6/10	3109/6.4/10	537/4.8/10
N 2.5×10^{13} G 5.2×10^{7}	175	320/11 /4	876/5.5/5	5470/6.4/5	550/6.2/4	303/8.4/5	920/6.4/5	2845/6.1/5	526/4.1/5
N 2.9×10^{13} G 6×10^{7}	75	315/4 /4	770/9.5/5	5637/16 /5	544/8.7/5	300/8.5/5	840/5 /5	3230/7.3/5	554/3.9/5
N 3.9×10^{13} G 6.5×10^{7}	-45	327/5 /5	816/4.6/5	5568/1.6/4	565/13 /4	338/4.8/5	936/9.5/5	3023/3.7/5	578/11 /5
N 1×10^{16} G 1.4×10^{10}	75	251/19 /4	800/10 /4	1830/4.1/4	320/3 /4	226/6.5/4	546/9.3/4	748/7.9/4	
Control	80	330/5.7/10	818/4.2/10	5564/7.4/10	589/5 /10	278/9.4/10	813/5.9/10	2932/[illegible]/10	598/6 /10
	260	294/8.1/10	862/2.8/10	5637/4.4/10	614/2.7/10	263/8.8/10	848/5.9/10	3008/4.3/10	622/3.4/10
N 5.3×10^{15} G 1.3×10^{10}	-65	192/7.4/4	640/6.9/4	2234/14 /5	406/11 /5	305/11 /5	858/4.6/5	1571/[illegible].6/5	359/8.1/4
N 6.7×10^{15} G 1.5×10^{10}	80	4[illegible]/6.5/5		1736/16 /5	216/8 /5	307/2.9/5		1068/1.4/5	256/6.7/5
N 8.5×10^{15} G 1.9×10^{10}	260	628/6.3/5		1218/14 /5	138/7.2/4	44[illegible]/10 /5		888/12 /4	165/10 /4
N 4.5×10^{16} G 7×10^{10}	80			906/14 /5	26/9.4/5			692/9.8/5	25/17 /5

(a) Data are given as $\overline{x}$/S.D./n, where $\overline{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\overline{x}$ and S.D.

(b) Test temperature 80 F.

Table B-51. PHYSICAL PROPERTIES OF COMPOUND 160-62[47]

Base Elastomer - Polyurethane

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	2084		335		660		68			
1. γ, Vac. 16 hrs., 70 F	13	6.4×10^6	996	-52	373	+12	427	-35	73	+5	+ 6	2
2. γ, Vac. 100 hrs., 70 F	14	6.1×10^7	820	-61	365	+ 9	340	-48	71	+3	+ 2	3
3. γ + UV, Vac.(2) 16 hrs., 95 F	15	5.7×10^6	640 118	-69 -94	350 51	+ 4.5 -85	290 360	-56 -46	70 70	+2 +2	- 1 - 4	4 5
4. γ, Vac.(3) 100 hrs., 70 F	16	5.0×10^7	764	-63	328	- 2.1	333	-50	72	+4	- 1	3
5. γ, Air 100 hrs., 70 F	17	6.1×10^7	1012	-51	344	+ 2.7	390	-41	70	+2	+ 4	1
6. γ + UV, Air(2) 100 hrs., 250 F	18	5.0×10^7	—	—	—	—	—	—	73	+5	-12	6

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Combined radiation intended

Table B-51. (Concluded)

Time effect: The samples underwent an initial cross-linking period after which chain scission was more predominant (Condition 1 vs. 2).

Atmosphere effect: The difference between air and vacuo irradiation appeared very small. The weight changes were also small, in view of the extensive degradation of some of the specimens.

Type irradiation effect: The effect of combined radiation was very greatly masked by the effect of the heat accompanying the desired ultraviolet radiation.

Observations: Condition 3, one specimen (upper) was covered with an iridescent discoloration on face toward UV lamp. Two specimens (lower) appeared to have partially melted and rehardened on that face. Condition 6, iridescent discoloration glazed surface with fine cracks on face toward UV lamp. All irradiated specimens exhibited a slight "tacky" condition on their edges and the broken ends.

Table B-52. EXPOSURE OF POLYURETHANE VULCANIZATE (Z72)[1] TO HIGH VACUUM AT VARIOUS TEMPERATURES[45]

Property Measured	Original	Exposed to Vacuum of 10^{-5} mm Hg for 56 Days at Room Temperature	158 F: Vacuum of 8×10^{-5} mm Hg for 7 Days	158 F: Air Oven for 7 Days	212 F: Vacuum of 7.8×10^{-6} mm Hg for 5 Days	212 F: Air Oven for 5 Days	300 F: Vacuum of 2.1×10^{-6} mm Hg for 5 Days	300 F: Air Oven for 5 Days
Tensile strength, psi	3250	3370	3470	3100	3360	3250	3540	1220
Modulus, psi at 300 per cent elongation	715	760	950	760	925	810	1960	945
Elongation, per cent	715	675	650	625	615	710	385	350
Hardness, Shore A	56	60	62	58	58	58	80	56
Strain, per cent elongation at 400 psi	219	204	188	214	195	175	89	160
Low temperature flexibility, ASTM D1043, T_{200}, F	-40	-38	-38	-37	—	—	-28	—
Weight change, per cent	—	-0.4	-1.9	—	-2.1	-1.5	-2.[illegible]	-2.0

Compounding Ingredient	Parts by Weight
Genthane S	100
Stearic Acid	0.2
Magnesium Oxide	4
DiCup 40 C	4
MAF Carbon Black	30
	138.2

Magnesium Oxide	4
DiCup 40 C	4
MAF Carbon Black	30
	138.2

TABLE B-53. FLUID SOAK IRRADIATION - EFFECTS ON TENSILE PROPERTIES[a] OF GENTHANE S-1 AND BUTADIENE-ACRYLONITRILE[48]

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation Temp, F	MIL-L-7808[b] Modulus at 100% Elongation, psi	MIL-L-7808[b] Ultimate, psi	4P3E[b] Modulus at 50% Elongation, psi	4P3E[b] Modulus at 100% Elongation, psi	4P3E[b] Ultimate, psi	Oronite 8515[b] Modulus at 100% Elongation, psi	Oronite 8515[b] Ultimate, psi
Genthane S-1 (Polyurethane)[c]								
Control[d]								
N 1.2-1.6 x 10^{14} G 3.0-3.3 x 10^{8}	80	131/4 /5	2816/12/5		176/9.8/5	2122/4.5/5		
N 1.3-1.4 x 10^{15} G 2.1-2.2 x 10^{9}	80						217/4 /5	3598/16 /5
N 1.1 x 10^{15} G 2.8 x 10^{9}	80			82/11/5		1968/15 /4		
Nitrile (Butadiene-Acrylonitrile)[c]								
Control[d]								
N 1.2-1.6 x 10^{14} G 3.0-3.3 x 10^{8}	80	257/21/5	3110/12/4		273/10 /5	1570/22 /4	464/11/5	2946/15 /5
N 1.3-1.4 x 10^{15} G 2.1-2.2 x 10^{9}	80						598/14/5	2562/7.3/5
N 1.1 x 10^{15} G 2.8 x 10^{9}	80			186/17/5		2036/14 /5		
N 9.3 x 10^{15} G 1.3 x 10^{10}	350			[illegible]/5		559/15 /5		

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.
(b) Immersion media.
(c) Test temperature 80 F.
(d) Control data lost.

TABLE B-54. FLUID SOAK IRRADIATION - EFFECTS ON TENSILE PROPERTIES[a] OF DISOGRIN, BUTYL RUBBER AND DU PONT VITON 441 [illegible][48]

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation Temp, F	Disogrin[b] IDSA 6865, 4P3E[c] Modulus at 100% Elongation, psi	Disogrin[b] IDSA [illegible] 4P3E[c] Modulus at 100% Elongation, psi	Disogrin[b] IDSA [illegible] 4P3E[c] Ultimate, psi	Butyl Rubber[b] MIL-L-7808[c] Modulus at 100% Elongation, psi	Butyl Rubber[b] MIL-L-7808[c] Ultimate, psi	Butyl Rubber[b] Oronite 8515[c] Modulus at 100% Elongation, psi
Control[d]							
N 1.1 x 10^{14} G 1.7 x 10^{8}	80						199/9.8/4
N 1.2-1.6 x 10^{14} G 3.0-3.3 x 10^{8}	80	781/4.7/5	1850/2.1/4	3513/11/4	18.5/5.2/4	127/15/5	

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation Temp, F	Du Pont Viton 441 [illegible] 205, 4P3E[c] Modulus at 100% Elongation, psi	205, 4P3E[c] Ultimate, psi	381, 4P3E[c] Modulus at 50% Elongation, psi	381, 4P3E[c] Modulus at 100% Elongation, psi	381, 4P3E[c] Ultimate, psi	882, 4P3E[c] Modulus at 100% Elongation, psi	882, 4P3E[c] Ultimate, psi
Control[d]								
N 1.2-1.6 x 10^{14} G 3.0-3.3 x 10^{8}	80	356/2.7/5	2303/12 /5		1220/5.2/6	2281/5.2/6	1147/5.2/6	1946/4.2/6
N 1.3-1.4 x 10^{15} G 2.1-2.2 x 10^{9}	80	701/7.5/5	2267/7.4/5					
N 1.1 x 10^{15} G 2.8 x 10^{9}	80			623/10/6		2133/4.6/6		

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of i[illegible] observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.
(b) Test temperature 80 F.
(c) Immersion media.
(d) Control data not reported.

(d) Control data not reported.

TABLE B-55. FLUID SOAK IRRADIATION - EFFECTS ON TENSILE PROPERTIES[a] OF GENTHANE 130R, THIOKCL ST, AND WADC-11[48]

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation Temp, F	Genthane 130R (Polyurethane)[b] MIL-L-7808[c] Modulus at 100% Elongation, psi	MIL-L-7808[c] Ultimate, psi	Mo[illegible]lus at [illegible]% [illegible]on, psi	4P3E[c] Modulus at 100% Elongation, psi	4P3E[c] Ultimate, psi	Oronite 8515[c] Modulus at 100% Elongation, psi	Oronite 8515[c] Ultimate, psi
Control[d]								
N 1.2-1.6 x 10^{14} G 3.0-3.3 x 10^{8}	80	267/9.7/5	2620/9.2/5		225/8.1/5	1192/7.9/5	305/2.9/3	3553/4 /3
N 1.3-1.4 x 10^{15} G 2.1-2.2 x 10^{9}	80						2d9/6.4/5	2816/2.9/5
N 1.1 x 10^{15} G 2.8 x 10^{9}	80			71/18/5		1033/1 9/4		

		Thiokol ST (Polysulfide)[b] MIL-L-7808[c] Modulus at 100% Elongation, psi	MIL-L-7808[c] Ultimate, psi	4P3E[c] Ultimate, psi	Oronite 8515[c] Modulus at 100% Elongation, psi	Oronite 8515[c] Ultimate, psi	WADC-11[b] 4P3E[c] Ultimate, psi
Control[d]							
N 1.1 x 10^{14} G 1.7 x 10^{8}	80	519/2.6/4	938/5.4/5		554/2.7/4	905/8.5/5	
N 1.2-1.6 x 10^{14} G 3.0-3.3 x 10^{8}	80	506/3.6/5	780/17 /5	151/16 /3			
N 1.3-1.4 x 10^{15} G 2.102.2 x 10^{9}	80				628/5.2/5	844/4.9/5	
N 1.1 x 10^{15} G 2.8 x 10^{9}	80						2038/12/5

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average [illegible]ue, S D = standard deviation of [illegible]vidual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.
(b) Test temperature 80 F.
(c) Immersion media.
(d) Control data not reported.

(d) Control data not reported.

TABLE 3-56. FLUID SOAK IRRADIATION - EFFECT ON TENSILE PROPERTIES[a] OF KIRKHILL MIL-R-68855 AND DU PONT LD-234[48]

Integrated Neutron Flux (N), n cm^{-2} (E >0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation Temp, F	Kirkhill MIL-R-68855[b] MIL-L-7808[c] Modulus at 100% Elongation, psi	Kirkhill MIL-R-68855[b] MIL-L-7808[c] Ultimate, psi	Kirkhill MIL-R-68855[b] 4P3E[c] Modulus at 50% Elongation, psi	Kirkhill MIL-R-68855[b] 4P3E[c] Modulus at 100% Elongation, psi	Kirkhill MIL-R-68855[b] 4P3E[c] Ultimate, psi	Du Pont LD-234[b] 4P3E[c] Modulus at 100% Elongation, psi	Du Pont LD-234[b] 4P3E[c] Ultimate, psi
Control[d]								
N 1.2-1.6 x 10^{14} G 3.0-3.3 x 10^{8}								
	80	445/2.5/5	1008/7.5/5		534/20/4	1225/5.7/4		
N 1.3-1.4 x 10^{15} G 2.1-2.2 x 10^{9}								
	80						791/2/6	183[illegible]/8.6/6
	350				223/20/5	485/17 /5		
N 1.[illegible] x 10^{15} G 2.8 x 10^{9}								
	80			88/12/5		425/9.7/4		

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.
(b) Test temperature 80 F.
(c) Immersion media.
(d) Control data not reported.

TABLE B-57. SILICONE RUBBERS - TENSILE PROPERTIES(a) OF DC-80 VERSUS TEMPERATURE AND IRRADIATION(48)

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation and Storage Temp, F	DC-80 (Methyl Vinyl) -65 F(b) Modulus at 50% Elongation, psi	-65 F(b) Ultimate, psi	80 F(b) Modulus at 50% Elongation, psi	80 F(b) Ultimate, psi	80 F(b) Ultimate Elongation, %	300 F(b) Modulus at 50% Elongation, psi	300 F(b) Ultimate, psi
Control								
	-65	417/4.3/5	1303/5.5/5		1155/8.8/5	359/8.8/4		
	80			303/2.8/5	1057/6.7/5	317/10 /5		
	350			321/5.0/5	1209/3.4/5	325/3 5/5	286/11 /8	538/11 /6
N 6.2 x 10^{13} G 8 x 10^{7}								
	-65	410/4 /5	1288/13 /5				277/1.4/5	558/15 /5
N 1.1 x 10^{14} G 1.3-1.4 x 10^{8}								
	80			278/3.7/5	1088/12 /5	303/9.2/5	348/2.2/4	
	350			347/7 /5	873/14 /5	201/15 /5	342/14 /5	535/16 /5
N 4.7-5.3 x 10^{14} G 6.3-8.3 x 10^{8}								
	-65	589/13 /5	1152/13 /5				383/5.2/5	537/8.8/5
	80			283/3 /5	1117/7.3/5	206/4.2/5	388/1.5/5	539/18 /5
N 0.7-1.0 x 10^{15} G 1.1 x 10^{9}								
	-65	765/5.3/5	1238/5.5/5				589/11 /5	638/12 /5
	350			524/6 /5	849/7.7/5		557/5.3/5	654/4 /5
N 1.0-1.3 x 10^{15} G 1.5/1.7 x 10^{9}								
	80						283/4.8/5	631/5.8/5
	350				813/8.9/5	29/37 /5		691/8.8/5

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature.

TABLE B-58. SILICONE RUBBERS - TENSILE PROPERTIES(a) OF DC-675 VERSUS TEMPERATURE AND RADIATION(18)

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation and Storage Temp, F	DC-675 (Methyl Phenyl Vinyl) -65 F(b) Modulus at 50% Elongation, psi	-65 F(b) Ultimate, psi	80 F(b) Modulus at 50% Elongation, psi	80 F(b) Ultimate, psi	80 F(b) Ultimate Elongation, %	300 F(b) Modulus at 50% Elongation, psi	300 F(b) Ultimate, psi
Control	-65	322/5.6/5	1090/8 /5		901/4.8/5	324/15 /5		
	80			212/5.9/5	992/3.5/5	335/3.9/5		
	350			288/2.4/5	951/7.8/5	308/7.7/5	212/5.4/10	533/12 /9
N 6.2 x 10^{13} G 8 x 10^{7}	-65	383/5.4/5	1005/7.8/5				264/4.2/5	481/13 /5
N 1.1 x 10^{14} G 1.3-1.4 x 10^{8}	80			205/12 /5	968/3.8/5	325/5.3/5	208/5.2/5	559/12 /5
	350				703/18 /5	218/11 /4	227/7.2/5	450/17 /5
N 4.7-5.3 x 10^{14} G 6.3-8.3 x 10^{8}	-65	646/2.8/5	944/14 /5				293/6.9/5	581/10.4/5
	80			287/11 /5	886/3.5/5	180/8.4/5	287/4 /5	574/11 /5
N 0.7-1.0 x 10^{15} G 1.1 x 10^{9}	-65	[illegible]29/10 /5	1109/6.3/5				547/5.4/5	603/4.4/5
	350			334/7.2/5	878/8.4/5	152/9.9/5	376/6.2/5	503/4.5/4
N 1.0-1.3 x 10^{15} G 1.5-1.7 x 10^{9}	80			510/0.6/5	938/8.7/5	136/16 /5	536/7.2/5	575/5 /5
	350				998/10 /5	38/17 /5		670/19 /5

(a) Data are given as $\overline{x}$/S.D./n, where $\overline{x}$ = average value, S.D. = standard deviation of [illegible] observation estimated from the range, and n = number of specimens used in calculating $\overline{x}$ and S.D.

(b) Test temperature.

TABLE B-59. SILICONE RUBBERS - TENSILE PROPERTIES(a) OF DC-916 VERSUS TEMPERATURE AND IRRADIATION(48)

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation and Storage Temp, F	DC-916 (Methyl Phenyl Vinyl) -65 F(b) Modulus at 50% Elongation, psi	-65 F(b) Ultimate psi	80 F(b) Modulus at 50% Elongation, psi	80 F(b) Ultimate, psi	80 F(b) Ultimate Elongation, %	300 F(b) Modulus at 50% Elongation, psi	300 F(b) Ultimate, psi
Control								
	-65	145/5.8/5						
	80			109/2.8/5	1504/4.3/10	508/3.9/10		
	350			148/11 /5			123/7.4/10	489/15 /10
N 6.2 x 10^{13} G 8 x 10^{7}								
	-65	362/3 /5					139/12 /5	655/7.7/5
N 1.1 x 10^{14} G 1.3-1.4 x 10^{8}								
	80			104/13 /4			132/4.2/5	658/7.9/5
	350				1330/3.8/5	584/3 /5		772/11 /5
N 4.7-5.3 x 10^{14} G 6.3-8.3 x 10^{8}								
	-65	246/0.6/5	1802/1.5/5				160/6.[illegible]/5	517/11 /5
	80			150/4.6/5	1134/6.1/5	455/3.3/5	171/8.0/5	[illegible]45/11 /5
N 0.7-1.0 x 10^{15} G 1.1 x 10^{9}								
	-65	359/7.7/5	1404/4.7/5				312/9.4/5	449/6.5/5
	350			237/9.3/5	1190/4.0/5	382/3.8/5	226/1.8/5	611/7.0/5
N 1.0-1.3 x 10^{15} G 1.5-1.7 x 10^{9}								
	80				1182/1.[illegible]/5	334/6.5/5		461/16 /5
	350				523/2[illegible] /5	45/28 /5		322/24 /5

(a) Data are given as $\overline{x}$/S.D./n, where $\overline{x}$ = average value, S.D. = standard deviation of i[illegible]vidual observation estimated from the range, and n = number of specimens used in calculating $\overline{x}$ and S.D.

(b) Test temperature.

TABLE B-60. *SILICONE RUBBERS - TENSILE PROPERTIES*[a] OF SE-361 VERSUS TEMPERATURE AND IRRADIATION[48]

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation and Storage Temp, F	SE-361 (Methyl Vinyl) -65 F[b] Modulus at 50% Elongation, psi	-65 F[b] Ultimate, psi	80 F[b] Modulus at 50% Elongation, psi	80 F[b] Ultimate, psi	80 F[b] Ultimate Elongation, %	300 F[b] Modulus at 50% Elongation, psi	300 F[b] Ultimate, psi
Control								
	-65	231/21 /5	1050/11 /5	269/23 /5	950/5.9/5	136/3.7/4		
	80			228/18 /5	967/3.1/5	126/6.8/5		
	350			313/19 /5	974/6.9/5	126/9.[illegible]/4	261/31 /10	561/20 /9
N 6.2 x 10^{13} G 8 x 10^{7}								
	-65	417/23 /5	1284/6.4/5				318/24 /5	547/18 /5
N 1.1 x 10^{14} G 1.3-1.4 x 10^{8}								
	80			343/19 /5	983/10 /5	109/12 /5	494/8.1/5	844/9 /5
	350			235/9.3/5	875/9 /5	121/7.8/5		571/4.5/5
N 4.7-5.3 x 10^{14} G 6.5-8.3 x 10^{8}								
	-65	752/19 /5	1239/19 /5				380/15 /5	613/15.9/5
	80			430/28 /5	977/5.6/5	90/9.1/3	505/13 /5	66[illegible]/18 /5
N 0.7-1.0 x 10^{15} G 1.1 x 10^{9}								
	-65		1354/1.8/5					740/12 /5
	350				349/2 /5		637/18 /5	723/5.4/5
N 1.0-1.3 x 10^{15} G 1.5-1.7 x 10^{9}								
	80				953/8.1/5	83/7.8/5		651/20 /5
	350				711/2.4/5	32/40 /5		711/10 /5

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature.

TABLE B-61. SILICONE PUBBERS - TENSILE PROPERTIES[a] OF SE-551 VERSUS TEMPERATURE AND IRRADIATION[48]

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation and Storage Temp, F	SE-551 (Methyl Phenyl) -65 F[b] Modulus at 50% Elongation, psi	-65 F[b] Ultimate psi	80 F[b] Modulus at 50% Elongation, psi	80 F[b] Ultimate, psi	80 F[b] Ultimate Elongation, %	300 F[b] Modulus at 50% Elongation, psi	300 F[b] Ultimate, psi
Control	-65	126/1.5/5	1404/ /1		955/18 /5	384/14 /5		
	80			85/5.1/5	976/20 /5	431/7.5/5		
	350			109/4.4/5	1098/4.7/5	398/5.4/5	116/17 /8	416/15 /10
N 6.2×10^{13} G 8×10^{7}	-65	127/12 /5					127/7.4/5	555/6.9/5
N 1.1×10^{14} G $1.3\text{-}1.4 \times 10^{8}$	80			118/14 /5	948/5.8/5	460/5.2/5	147/7.9/5	487/11 /5
	350				928/15 /5	277/12 /5	146/9.1/5	452/15.8/5
N $4.7\text{-}5.3 \times 10^{14}$ G $6.3\text{-}8.3 \times 10^{8}$	-65	283/7 /5	1515/8.6/5				219/9.6/5	580/6.[illegible]/5
	80			182/3.8/5	1078/9.2/5	268/12 /5	232/22 /5	4[illegible]8/25 [illegible]
N $0.7\text{-}1.0 \times 10^{15}$ G 1.1×10^{9}	-65	535/6.1/5	1259/3.1/5				398/8.6/5	466/17 /5
	350			229/6.2/5	1088/7.5/5	184/15 /5	274/3.9/5	577/15 /5
N $1.0\text{-}1.3 \times 10^{15}$ G $1.5\text{-}1.7 \times 10^{9}$	80			245/13 /5	883/8.9/5	177/21 /5	373/9.2/5	477/13 /5
	350				808/10 /5	75/13 /4		544/15 /5

(a) Data are given as $\bar{X}$/S.D./n, where $\bar{X}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{X}$ and S.D.

(b) Test temperature.

TABLE B-62. SILICONE RUBBERS - TENSILE PROPERTIES(a) OF LS-53 VERSUS TEMPERATURE AND IRRADIATION(48)

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation and Storage Temp, F			LS-53(b)				
		Modulus at 50% Elongation, psi	Ultimate, psi	Modulus at [illegible] Elongation, psi	Ultimate, psi	Ultimate Elongation, %	Modulus at 50% Elongation, psi	Ultimate, psi
Control	-65	361/5.5/5	2052/2.4/5		1324/3.2/5	2?7/5.4/5		
	80			2?2/3 /5	1283/12 /5	253/8.5/5		
	350			249/4.7/5	1354/3.4/5	237/0.9/5	207/14 /10	472/?.7 /10
N 6.2 x 10^{13} G 8 x 10^{7}	-65	436/2.7/5	2094/3.1/5				214/17 /5	543/6.1/4
N 1.1 x 10^{14} G 1.3-1.4 x 10^{8}	80			233/9.2/5	1169/?.3/5	238/1.8/5	245/9.5/5	507/7.4/5
	350			263/6.5/5	853/11 /5	174/13 /4	263/6.2/5	292/24 /5
N 4.7-5.3 x 10^{14} G 6.3-8.3 x 10^{8}	-65	882/8.4/5	1783/6.1/5				313/11 /5	3??/4.3/5
	80			333/4 /5	751/6.5/5	120/5.4/5	318/6.3/2	327/8 4/5
N 0.7-1.0 x 10^{15} G 1.1 x 10^{9}	-65	717/[illegible] /5	1076/6.1/5					270/3.7/[illegible]
	350				626/5.6/4	71/3.5/4	502/11 /2	328/27 /5
N 1.0-1.3 x 10^{15} G 1.5-1.7 x 10^{9}	80				514/13 /5	74/17 /4		307/14 /5
	350				482/17 /5	20/32 /5		243/20 /5

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

TABLE B-63. SILICONE RUBBERS - TEAR STRENGTH(a) VERSUS IRRADIATION AND TEMPERATURE(48)

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation and Storage Temp, F	Tear Strength, lb/in.					
		DC-80(b)	DC-675(b)	DC-916(b)	SE 361(b)	SE 551(b)	LS-53(b)
Control	80	101/12 /5	120/20 /5	242/19 /5	27/14 /5	110/18 /5	74/23 /5
N 6.2×10^{13} G 8×10^{7}	-65	89/11 /5	121/13 /5	204/14 /5	29/14 /5		95/3.8/2
N 6×10^{13} G 1.3×10^{8}	-65	76/20 /5	99/13 /5	156/15 /5	24/36 /5	75/7.1/4	
	80	67/7.7/5	78/11 /5	[illegible]/16 /5	20/8.6/4	67/17 /4	
N 1×10^{14} G 1.3×10^{8}	350	73/30 /4	86/15 /5	158/4 /4	22/27 /5	64/4 /5	59/13 /4
N 1.1×10^{14} G 1.4×10^{8}	80	92/17 /5	95/7.7/5	179/8.9/5	25/[illegible] /5	86/9.1/4	
N 2.8×10^{14} G 3.5×10^{8}	-65	69/8.1/4	64/11 /5	151/18 /5	28/35 /5	63/16 /5	
	80	66/11 /5	80/9.1/5	166/18 /5	20/8.6/5	50/15 /5	
N 1×10^{15} G 1.1×10^{9}	65	9/19 /5		115/11 /4	31/22 /5	53/18 /4	46/27 /3
N 1×10^{15} G 1.5×10^{9}	80	11/24 /5	25/7.8/4	181/12 /5	17/18 /5	70/12 /5	
N 1.3×10^{9} G 1.7×10^{9}	350	3/43 /5	4/22 /5	38/21 /[illegible]	6/7.2/5	21/6.2/5	7/6.9/4

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

TABLE B-64. SILICONE RUBBERS - TENSILE AND SHEAR PROPERTIES[a] OF DC-916 AND SE-555 VERSUS IRRADIATION[48]

Integrated Neutron Flux (N), n cm^{-2}[b] (E > 0.33 Mev)[b] Gamma Exposure (G), ergs g^{-1} (C)[b]	Days Tested After Irradiation	DC-916 (Methyl Phenyl Vinyl)[c]				SE-555 (Methyl Phenyl Vinyl)[c]			
		Ultimate, psi	Ultimate Elongation, %	Compression Set, %	Tear Strength, lb/in.	Ultimate, psi	Ultimate Elongation %	Compression Set, %	Tear Strength, lb/in.
Control									
	14	1504/4.[illegible]/10	508/3.9/10	12.9/8.6/6	165 /4.3/10	1840/6 /10	631/2.6/10	25/4.8/6	265/3.5/9
	25	1589/7.8/8	524/4.7/8			1580/14 /7	496/7.5/7		
N 3 x 10^{15} G 6.5 x 10^{9}									
	14	263/9.3/10	12/14 /10	109 /6.2/6	14.7/27 /10	547/17 /10	28/12 /10	113/3.5/6	20/28 /10
	21	311/9.1/8	19/19 /8			557/16 /8	51/21 /8		
N 5.5 x 10^{15} G 1.2 x 10^{10}									
	25	260/[illegible]3 /10	10/ /10	112 /3.9/6	10 /23 /10	482/10 /10	32/11 /10	112/3.2/6	14/24 /10
	32	331/[illegible]/8	15/ /8			514/9.9/8	31/21 /8		

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D

(b) Irradiation temperature 80 F

(c) Test temperature 80 F.

TABLE B-65. ELASTOMERS - TENSILE PROPERTIES OF DC-916 VERSUS POSTIRRADIATION STORAGE TIME(48)

Integrated Neutron Flux (N), n cm^{-2} (E > 0.29 Mev)(b) Gamma Exposure (G), ergs g^{-1} (C)	Days Tested After Irradiation	DC-916 (Methyl Phenyl Vinyl)(c) Modulus, psi At 100% Elongation	At 200% Elongation	At 300% Elongation	Ultimate, psi	Ultimate Elongation, %
Control	2	184/5.2/8	349/4.1/8		12[illegible]2/7.6/8	494/7 /8
N 7.2 x 10^{13} G 4.7 x 10^{8}						
	2	234/6.8/5			1201/6.9/5	406/3.2/5
	5	219/7.[illegible]/5	450/8.7/5		1070/5.9/5	378/9.9/5
	11	242/3.1/4	483/12 /4	796/12 /4	1262/13 /4	391/2.4/4
	30	229/5.7/5	456/6.2/5	788/6 /5	1155/5.8/5	392/8.7/5
N 2.4 x 10^{14} G 1.3 x 10^{9}						
	2	481/7.8/5			804/2.7/5	183/2.2/[illegible]
	5	513/8.6/5			754/5.8/5	146/3.9/5
	11	555/6.3/5			773/7 /5	142/9.2/5
	30	493/14 /5			780/7.2/5	158/6.7/5

(a) Data are given as $\bar{x}$/S.D., n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Irradiation and storage temperature 75 F.

(c) Test temperature 75 F.

TABLE B-66. NITRILE-SILICONE RUBBER NSR-X5602 - ENGINEERING TEST PROPERTIES[a] VERSUS IRRADIATION TEMPERATURE AND IMMERSION MEDIA (AIR AND JP4 FUEL)[48]

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation Temp, F	NSR-X5602 (Nitrile Silicone)[b] Air[c] Modulus at 50% Elongation, psi	Ultimate, psi	Ultimate Elongation, %	Compression Set, %	Slope of Load Deflection Curve, lb/in.	JP 4 Fuel[c] Modulus at 50% Elongation, psi	Ultimate, psi	Ultimate Elongation, %
Control	80	144/2.1/5	978/9.2/5	270/5.9/6	14.5/9.1/6	1107/8.6/6	134/11/5	314/11 /5	102/8.4/5
		148/10 /8	994/7.2/8	283/5.7/8	18.2/5.9/6	1187/5.3/6			
N 0.9-1.1 x 10^{13} G 1.3-1.6 x 10^8									
	-65	182/7.1/10	1027/7.4/10	231/8.4/10	31.4/5 /4	1260/1.5/4			
	80				27.7/6.8/4	1250/6.2/4			
	260				53.9/2.7/4	1690/5.4/4			
N 7.0-7.7 x 10^{14} G 8 x 10^8									
	-65				65.6/3.6/4	2190/3.6/4			
	80	208/6.4/5	778/9.9/5	164/2.7/5	62.7/4.3/4	2180/[illegible]/4			
N 1.5 x 10^{15} G 1.2 x 10^9									
	260	545/ /1	[illegible]/3.7/5	69/3.5/5	99 /2.5/4	5563/1.3/4			
N 5.0-8.0 x 10^{15} G 1.1-1.3 x 10^{10}									
	-65		545/12 /9	16/22 /8	95 /2.1/4	11,525/3.4/4			
	80		118/13 /9	16/22 /8	100 /6.3/4	12,350/12 /4		250/9.4/8	53/10 /8
	260		103/23 /8	<5/ /7	108 /2.7/4	13,375/13 /4			
N 4.5 x 10^{16} G 7 x 10^{10}									
	80		221/14 /7	<5/ /8					

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of [illegible] observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.
(b) Test temperature 80 F.
(c) Immersion media.

(c) Immersion media.

TABLE B-67. NITRILE-SILICONE RUBBER NSR-X5602 - ENGINEERING TEST PROPERTIES[a] VERSUS IRRADIATION TEMPERATURE AND IMMERSION MEDIA (ORONITE 8515 AND MIL-L-7808)[48]

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation Temp, F	NSR-X5602 (Nitrile Silicone)[b]					
		Oronite 8515[c]			MIL-L-7808[c]		
		Modulus at 50% Elongation, psi	Ultimate, psi	Ultimate Elongation, %	Modulus at 50% Elongation, psi	Ultimate, psi	Ultimate Elongation, %
Control							
	80	122/9.9/5	547/7.4/5	183/5.9/5	110 /20 /5	410/12/5	146/12 /4
	260	123/12 /5	554/16 /5	178/12 /5	115 /10 /5	390/12/5	153/14 /5
N 0.9-1.1 x 10^{13} G 1.3-1.6 x 10^{8}							
	80	156/8.1/10	449/8 /10	133/6.1/10	80 /9.7/9	256/16/10	150/6.5/10
	260	160/16 /9	499/11 /10	138/5.9/10	76.5/13 /8	278/10/10	151/11 /10
N 7.0-7.7 x 10^{14} G 8 x 10^{8}							
	80	201/4.7/5	506/4.3/5	117/3.7/5	87 /14 /5	134/18/5	122/7.3/3
N 1.3 x 10^{15} G 1.3 x 10^{9}							
	260	191/18 /5	383/5.7/4	85/6.9/3			
N 5.0-8.0 x 10^{15} G 1.1-1.3 x 10^{10}							
	80		320/24 /8	23/15 /8			

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

(c) Immersion media.

TABLE B-68. COMPRESSION CYCLING OF ELASTOMERS[a] DURING IRRADIATION[48]

Integrated Neutron Flux (N), n cm^{-2} (E > 0.33 Mev)[b] Gamma Exposure (G), ergs g^{-1}(C)[b]	Irradiation Time, hr	Noncycled Uncompressed Load-Deflection, lb/in.	Noncycled Compressed Load-Deflection, lb/in.	Noncycled Compressed Compression Set, %	Cycled Compressed[c] Load-Deflection, lb/in.	Cycled Compressed[c] Compression Set, %
NSR-X5602[d]						
Control		1307/9 /3	1230/4.8/8	16.4/16.4/8	1333/1.8/3	7.2/16 /3
N 2×10^{14} G 4×10^{8}	1	2000/3.9/4	1470/6.6/4	48.1/11 /4	1627/2.9/3	27.2/18 /3
	3	2040/5.7/4	1410/6.9/4	48.8/4.5 /4	1600/4.4/3	11.9/ /1
Hycar 1001[d]						
Control		1720/2.8/3	1785/3.3/8	13.3/14 /4	1750/2.1/3	01-14
N 3.8×10^{14} G 4.8×10^{8}	1	1990/2.9/4	2070/5.4/4	40.1/3.8 /4	1820/7.8/3	13.3/14/2
	3	1890/0 /4	2.60/2.3/4	51.4/9 /4	1930/1 /3	
DC-916[d]						
Control		1544/2.3/4	1663/4.4/4	24.5/27.6/4	1675/2.7/2	15.3/ .1/2
3×10^{14} G 3.3×10^{8}	1	2056/7.1/4	2431/9 /4	54 /11 /4		
N 2.8×10^{14} G 4.2×10^{8}	3	1968/6.2/4	2363/6.2/4	51.1/12 /4		
N 4×10^{14} G 4.5×10^{8}					2275/3.9/2	54.6/1.2/2
N 3.3×10^{14} G 5.3×10^{8}	3				2450/7.3/2	43.3/1.6/2

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Ambient radiation temperature.

(c) Number of cycles are as follows:

Material	Power Level	Number of Cycles: Before Irradiation	Number of Cycles: During Irradiation	Number of Cycles: After Irradiation	Number of Cycles: Total
NSR-X5602	Control				14,000
	3000 kw, 1 hr	8,600	4,460	920	13,980
	1000 kw, 1 hr	920	11,680	900	11,700
Hycar 1001	Control				10,800
	3000 kw, 1 hr	3,600	3,600	3,600	10,800
	1000 kw, 3 hr	900	10,800	--	11,700
DC-916	Control				5,400
	3000 kw, 1 hr	900	3,600	900	5,400
	1000 kw, 3 hr	9 900	10,800	900	12,600
	Control				12,600

(d) Test temperature, 80 F.

Table B-69. PERCENT WEIGHT LOSS FOR SILICONE RUBBER UNDER VACUUM-THERMAL CONDITIONS[31]

Silicone Rubber and Manufacturer	Weight Loss, percent							
	Temperature 105°F				Temperature, 300°F			
	Time, days				Time, days			
	1	4	7	10	1	4	7	10
RTV 891, Dow Corning Corp.	0.50	0.68	0.74	-	1.49	1.73	1.80	-
Silicone, Lord Mfg. Co.	0.32	0.40	0.43	0.43	0.70	0.93	1.02	1.02
RTV-60, General Electric Co.	-	-	-	-	1.05	1.30	1.36	-
PR-1930-1/2, Products Research								
Ambient temperature cure	0.79	0.91	0.97	-	1.64	1.86	1.96	-
Post cured 6 hours, 300°F	0.14	0.19	0.25	-	0.77	1.00	1.12	-
Silicone Rubber, Nylon Reinforced Irvington Division, MMM Co.	0.58	0.79	0.86	-	1.48	1.71	1.78	-

Pressure 10^{-6}

TABLE B-70. WEIGHT LOSS IN VACUUM, PRESSURE <5 x 10^{-6} mm Hg(17)

Material	Composition	Total Weight Loss to Stationary State (grams/cm^2) 50 C	Total Weight Loss to Stationary State (grams/cm^2) 100 C	Time to Stationary State (hours) 50 C	Time to Stationary State (hours) 100 C	Stationary State Weight Loss Rate (grams/cm^2/hour) 50 C	Stationary State Weight Loss Rate (grams/cm^2/hour) 100 C
		Polyolefin					
Irradiated polyolefin Wire insulation (Rayolin N 102E)	Radiation cross-linked polymers with additives	8.5–11 x 10^{-5}		138		4.7–7.3 x 10^{-8}	
Irradiated polyolefin Shrinkable tubing Type RNF RT 201	Radiation cross-linked polymers with additives	4.6 x 10^{-5}	4.3 x 10^{-4}	138	144	6.5 x 10^{-8}	3.8 x 10^{-7}
Irradiated polyolefin Experimental type	Radiation cross-linked polymers with additives	1.1 x 10^{-4}	3.5–4.0 x 10^{-3}	138	191	1.7–3.4 x 10^{-7}	8.0–8.3 x 10^{-6}
		Nylon					
Zytel 101	Standard grade nylon	2.8 x 10^{-4}	7.5 x 10^{-4}	188	104	3.4 x 10^{-7}	1.5 x 10^{-5}
Zytel 31	Electrical grade nylon	2.2 x 10^{-4}	6.3 x 10^{-4}	141	104	3.2 x 10^{-7}	1.6 x 10^{-6}
Zytel 105	Carbon black filled 101	1.6 x 10^{-4}	6.3 x 10^{-4}	141	104	1.2 x 10^{-7}	1.2 x 10^{-6}
		Polyacetal					
Delrin 500	Standard grade resin	3.0 x 10^{-4}	5.3 x 10^{-4}	168	104	2.0 x 10^{-7}	2.0 x 10^{-6}
Delrin 507	Carbon black filled resin	3.6 x 10^{-4}	5.6 x 10^{-4}	188	104	5.0 x 10^{-7}	1.6 x 10^{-6}
		Diallyl Phthalate (DAP)					
FS-5	Meta form, short glass fiber filled	2.6 x 10^{-4}	6.5 x 10^{-4}	55	88	1.5 x 10^{-6}	2.1 x 10^{-6}
3-2-530	Meta form, long glass fiber filled	1.1 x 10^{-4}	4.2 x 10^{-4}	55	88	6.3 x 10^{-7}	1.2 x 10^{-6}

TABLE [illegible]. (Continued)

Material	Composition	Total Weight Loss to Stationary State (grams/cm^2) 50 C	100 C	Time to Stationary State (hours) 50 C	100 C	Stationary State Weight Loss Rate (grams/cm^2/hour) 50 C	100 C
52-01	Ortho form, short glass fiber filled	1.3×10^{-4}	3.1×10^{-4}	55	64	7.3×10^{-7}	1.6×10^{-6}
1-530	Ortho form, long glass fiber filled	1.0×10^{-4}	4.1×10^{-6}	55	64	8.0×10^{-7}	1.2×10^{-6}
1-503	Ortho form, orlon filled	1.2×10^{-4}	5.1×10^{-4}	55	88	8.4×10^{-7}	1.1×10^{-6}
		Epoxy					
Epiall 1288 epoxy molding compound	Epoxy molding compound, glass fiber filled	3.9×10^{-5}	4.2×10^{-4}	55	64	1.6×10^{-7}	6.6×10^{-7}
Epiall 1459 epoxy molding compound	Epoxy molding compound, mineral filled	3.8×10^{-5}	1.5×10^{-4}	55	64	2.6×10^{-7}	4.7×10^{-7}
Devcon F epoxy (room temperature cure)	Aluminum filled (80 per cent by weight) epoxy	7.0×10^{-4}	1.0×10^{-3}	25	28	9.1×10^{-7}	1.8×10^{-6}
Armstrong epoxy (room temperature cure)	Unmodified polyamid cured epoxy system	1.8×10^{-4}	1.4×10^{-3}	25	28	3.8×10^{-6}	6.4×10^{-5}
Permacel epoxy type PRH 102 (cured 3 hours at 60 C)	Three parts variable flexibility epoxy	3.2×10^{-4}	2.3×10^{-3}	25	28	6.3×10^{-6}	2.9×10^{-5}
Permacel epoxy type FR 3935 (room temperature cure)	Modified, polyamid cured epoxy system	7.1×10^{-4}	4.0×10^{-3}	25	28	9.8×10^{-6}	$3.7\text{-}4.1 \times 10^{-5}$
Permacel epoxy (type PRH 102) (room temperature cure)	Three parts variable flexibility epoxy	6.6×10^{-4}	3.4×10^{-3}	25	28	1.0×10^{-5}	3.4×10^{-5}

TABLE B-70. (Continued)

Material	Composition	Total Weight Loss to Stationary State (grams/cm^2) 50 C	100 C	Time to Stationary State (hours) 50 C	100 C	Stationary State Weight Loss Rate (grams/cm^2/hour) 50 C	100 C
		Phenolic Laminates					
Phenolic laminate grade XX natural	Phenolic laminate, paper filler	1.4–1.5 $\times 10^{-3}$	3.5×10^{-3}	138	161	3.7–4.4 $\times 10^{-6}$	8.9×10^{-6}
Phenolic laminate grade LB 103	Phenolic laminate, cotton fabric MoS_2 impregnated	3.7–3.8 $\times 10^{-3}$	5.7–5.8 $\times 10^{-3}$	138	161	3.9–4.2 $\times 10^{-6}$	3.2–3.4 $\times 10^{-5}$
Phenolic laminate grade LBB natural	Phenolic laminate, cotton fabric	2.3–2.3 $\times 10^{-3}$	4.6–4.8 $\times 10^{-3}$	138	161	4.8–5.1 $\times 10^{-6}$	3.8–4.3 $\times 10^{-6}$
		Silicone					
Dow RTV 521 silicone rubber (room temperature cure)	Cross-linked silicone resins with various fillers ($CaCo_3$, SiO_2, and FeO_2)	4.5×10^{-3}		68		1.6×10^{-5}	
Dow RTV 503 silicone rubber (room temperature cure)	Cross-linked silicone resins with various fillers ($CaCo_3$, SiO_2, and FeO_2)	4.2×10^{-3}		68		2.3×10^{-5}	
GE RTV 40 silicone rubber (room temperature cure)	Cross-linked silicone resins with various fillers ($CaCo_3$, SiO_2, and FeO_2)	5.0×10^{-3}		68		2.7×10^{-5}	
GE RTV 60 silicone rubber (room temperature cure)	Cross-linked silicone resins with various fillers ($CaCo_3$, SiO_2, and FeO_2)	$5.3 \times 10^{-}$[illegible]		68		2.8×10^{-5}	

TABLE B-79 (Continued)

Material	Composition	Total Weight Loss to Stationary State (grams/cm^2) 50 C	Total Weight Loss to Stationary State (grams/cm^2) 100 C	Time to Stationary State (hours) 50 C	Time to Stationary State (hours) 100 C	Stationary State Weight Loss Rate (grams/cm^2/hour) 50 C	Stationary State Weight Loss Rate (grams/cm^2/hour) 100 C
Dow RTV 501 silicone rubber (room temperature cure)	Cross-linked silicone resins with various fillers ($CaCo_3$, SiO_2, and FeO_2)	5.8×10^{-3}		58		3.7×10^{-5}	
GE RTV 11 silicone rubber (room temperature cure)	Cross-linked silicone resins with various fillers ($CaCo_3$, SiO_2, and FeO_2)	4.3×10^{-3}		44		3.7×10^{-5}	
GE LTV 602 silicone potting compound (cured 16 hours at 100 C)	Clear silicone potting compound	1.2×10^{-2}		44		1.0×10^{-4}	
Dow RTV 5313-5314 silicone potting compound (room temperature cure)	Cross-linked silicone resins with various fillers ($CaCo_3$, SiO_2, and FeO_2)	4.3×10^{-2}		68		3.8×10^{-4}	

Table B-71. EXPOSURE OF SILICONE ELASTOMERS TO HIGH VACUUM AT VARIOUS TEMPERATURES[9]

Property Measured	Original	Exposed to Vacuum of 7.8×10^{-6} mm Hg for 5 days at Room Temperature	400°F		500°F		600°F		700°F	
			Vacuum of 1.9×10^{-5} mm Hg for 5 Days	Air Oven for 5 Days	Vacuum of 1.4×10^{-5} mm Hg for 5 Days	Air Oven for 5 Days	Vacuum of 1.7×10^{-5} mm Hg for 5 Days	Air Oven for 5 Days	Vacuum of 3.1×10^{-5} mm Hg for 5 Days	Air Oven for 5 Days
				Silicone SE 33 (Z84) (1)						
Tensile Strength, psi	710	740	770	550	690	400	700	390	Too brittle to test	Too brittle to test
Modulus, psi at 100% E	110	110	130	390	590	100	240	-	Too brittle to test	Too brittle to test
Elongation, percent	260	250	230	190	210	190	230	110	Too brittle to test	Too brittle to test
Hardness, Shore A	48	46	51	44	53	42	56	81	Too brittle to test	Too brittle to test
Strain, percent E at 200 psi	98	96	89	100	73	110	Broke	Broke	Too brittle to test	Too brittle to test
Change in weight, percent	-	-0.7	-1.8	-0.4	-3.2	-2.7	-10.3	-20.3	-45	Too brittle to test
				Silicone W96 (Z69 FCT) (1)						
Tensile Strength, psi	740	640	680	660	700	330	600	370	300	Too brittle to test
Modulus, psi at 100% E	375	310	570	440	470	-	360	-	-	Too brittle to test
Elongation, percent	220	210	130	160	160	80	150	40	70	Too brittle to test
Hardness, Shore A	7[illegible]	77	78	80	78	83	74	87	89	Too brittle to test
Strain, percent E at 200 psi	19	19	17	17	14	21	46	-	-	Too brittle to test
Change in weight, percent	-	-0.1	-1.6	-2.0	-3.0	-5.[illegible]	-[illegible].4	-14.7	-23	Too brittle to test

(1) See Table B-1 for formulation.

Table B-72. PRESS AND POST CURE SCHEDULES OF THE SILICONES USED IN THE IRRADIATION STUDIES[47]

Compound	Curing Data
39-62	Conductive silicone; post cure 24 hours at 410°F
56-62	Press cure 10 minutes at 250°F; post cure 3 hours at 400°F
58-62	Press cure 10 minutes at 250°F; post cure 24 hours at 480°F
105-62	Press cure 5 minutes at 240°F; post cure 24 hours at 480°F
106-62	Post cure 12 hours at 480°F
107-62	Post cure 24 hours at 480°F
109-62	Post cure 4 hours at 480°F
110-62	Post cure 16 hours at 300°F
111-62	Post cure 24 hours at 480°F
120-62	Room temperature vulcanizing silicone
147-62[a]	Room temperature vulcanizing silicone
148-62[b]	Room temperature vulcanizing silicone
149-62[c]	Low-density room-temperature vulcanizing silicone

(a) 96 parts compound, 4 parts curing agent

(b) 100 parts compound, 0.5 parts Thermolite T-12

(c) 100 parts compound, 10 parts accelerator

Table B-73. PHYSICAL PROPERTIES OF COMPOUND 105-62[47]

Base Elastomer - Silicone. Type - Dimethyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	819				62		83			
1. γ, Vac. 16 hrs., 70 F	1A	5.7×10^6	836	+ 2.1		- 9.6(3)	70	+13	84	+1	—	1
2. γ, Vac. 100 hrs., 70 F	2	6.2×10^7	1050	+28		+298(3)	20	-68	92	+9	+6	6
3. γ, Vac.(4) 16 hrs., 70 F	11	6.4×10^6	806	- 1.6		+ 65(3)	37	-40	85	+2	Nil	3
4. γ + UV, Vac.(2) 100 hrs., 335 F	7	6.1×10^7	1250	+53		+250(3)	27	-46	91	+8	-1	5
5. γ, Air 100 hrs., 70 F	5	3.4×10^7	1210	+48		+205(3)	30	-52	87	+4	+1	4
6. γ, Air(4) 100 hrs., 70 F	6	3.8×10^7	1012	+24		+350(3)	1[illegible]	-.3	86	+3	+13	7
7. γ, Air 16 hrs., 70 F	1	$[illegible].5 \times 10^6$	794	- 3.1		- 16(3)	72	+16	85	+2	—	2

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Table B-73. (Concluded)

<u>Time effect</u>: This compound showed a slight tendency toward chain scission at 16 hours in Conditions 1 and 7. Cross-linking predominated as exposure time increased. Comparison of Conditions 1 and 7 with 3 showed a possible "threshold dose" after which cross-linking becomes predominant.

<u>Atmosphere effect</u>: Differences were slight between radiation in air and vacuo. This compound showed initial scission in both air and vacuo at low dosages. Weight changes were not significant.

<u>Type irradiation effect</u>: The tensile strength was increased by combined irradiation. The 100 per cent modulus and ultimate elongation changes were decreased, and the hardness change remained the same in a comparison of Conditions 4 and 2.

<u>Observations</u>: Condition 4, grey-brown discoloration on face toward UV lamp. Condition 6, brown stains on specimens.

Table B-74. PHYSICAL PROPERTIES OF COMPOUND 106-62^{47}

Base Elastomer - Silicone, Type - Dimethyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	1216		193		387		58			
1. γ, Vac. 16 hrs., 70 F	1A	5.7×10^6	1270	+ 4.4	180	- 6.8	410	+ 5.9	54	- 4	---	1
2. γ, Vac. 100 hrs., 70 F	2	6.2×10^7	600	-51	—	+664(3)	47	-88	74	+16	+33	5
3. γ, Vac. 16 hrs., 70 F	11	6.4×10^6	1110	- 8.3	385	+100	230	-41	61	+ 3	+ 1	3
4. γ + UV, Vac.(2) 100 hrs., 335 F	7	6.1×10^7	288	-76	—	+894(3)	13	-97	82	+24	Nil	6
5. γ, Air 100 hrs., 70 F	5	3.4×10^7	1106	- 9.0	1016	+426	120	-69	78	+20	+ 2	4
6. γ, Air(4) 100 hrs., 70 F	6	3.8×10^7	466	-62	—	+355(3)	53	-86	78	+20	+ 7	4
7. γ, Air 16 hrs., 70 F	1	7.5×10^6	1333	+ 9.6	334	+ 73	260	-33	61	+ 3	---	2

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Table B-74. (Concluded)

<u>Time effect</u>: Time effects were pronounced for all properties. This compound apparently undergoes an initial period of chain scission in vacuo (Condition 1).

<u>Atmosphere effect</u>: The cross-linking was more pronounced in vacuo than in air except during the sixteen hour period (Condition 1) where the specimens exposed in vacuo apparently underwent a slight amount of scission. Specimen weight changes were insignificant.

<u>Type irradiation effect</u>: Combined radiation was more severe than straight gamma radiation, as evident from larger changes in all properties.

<u>Observation</u>: Condition 4, discoloration on face toward UV lamp.

Table B-75. PHYSICAL PROPERTIES OF COMPOUND 120-6247

Base Elastomer - Silicone, Type - Dimethyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	674		503		147		62			
1. γ, Vac. 16 hrs., 70 F	1A	5.7×10^6	623	- 7.6	584	+ 16	123	-16	63	+ 1	—	1
2. γ, Vac. 100 hrs., 70 F	2A	5.0×10^7	573	-15	—	+100(3)	57	-61	75	+13	—	4
3. γ, Vac.(4) 16 hrs., 70 F	11	6.4×10^6	599	-11	582	+ 16	103	-30	65	+ 3	-2	2
4. γ + UV, Vac.(2) 100 hrs., 115 F	7	6.1×10^7	601	-11	—	+139(3)	50	-66	76	+14	-6	6
5. γ, Air 100 hrs., 70 F	5	3.4×10^7	688	+ 2.1	—	+ 95(3)	70	-52	72	+10	+2	3
6. γ, Air(4) 100 hrs., 70 F	6	3.8×10^7	637	- 5.5	—	+139(3)	53	-64	75	+13	+5	5

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Table B-75. Concluded)

Time effect: The compound does not show the "threshold" effect apparent in other compounds. The cross-linking increased with exposure time.

Atmosphere effect: There was little apparent difference due to atmosphere. The compound showed slight weight gains in air and slight losses in vacuo.

Type irradiation effect: There was little difference in properties produced by combined and straight gamma radiation as evident from comparison of Conditions 2 and 4.

Observation: Condition 4, slight darkening on both faces of specimens.

Table B-76. PHYSICAL PROPERTIES OF COMPOUND 147-62[47]

Base Elastomer - Silicone, Type - Dimethyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	282		203		167		51			
1. γ, Vac. 16 hrs., 70 F	14	5.7×10^6	396	+40	364	+ 79	113	-32	57	+ 6	—	2
2. γ, Vac. 100 hrs., 70 F	2	6.2×10^7	541	+92	—	+344(3)	60	-64	73	+22	-18	4
3. γ, Vac.(4) 16 hrs., 70 F	11	6.4×10^6	350	+24	336	+ 66	100	-40	61	+10	- 2	1
4. γ + UV, Vac.(2) 100 hrs., 335 F	7	6.1×10^7	409	+45	—	+444(3)	37	-77	74	+23	-15	5
5. γ, Air 100 hrs., 70 F	5	3.4×10^7	211	-25	—	+352(3)	23	-86	68	+17	- 8	3
6. γ + UV, Air(4) 100 hrs., 70 F	6	3.8×10^7	489	+73	—	+323(3)	57	-66	71	+20	- 2	3

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Table B-76. (Concluded)

Time effect: Radiation effects became more severe with increasing exposure. This compound did not show the "threshold" effect apparent in other compounds.

Atmosphere effect: The radiation effects were similar in vacuo and air, except for tensile strength during straight gamma radiation, which showed a marked increase in vacuo versus a marked decrease in air. Straight gamma radiation in vacuo produced slightly greater changes in hardness than in air, and combined radiation in vacuo produced greater changes in modulus, elongation, and hardness than in air. The compound showed a consistent weight loss, greater in vacuo than in air.

Type irradiation effect: The effect of combined radiation appeared to be slightly greater than that of straight gamma radiation.

Observation: Condition 4, moderate browning on face toward UV lamp.

Table B-77. PHYSICAL PROPERTIES OF COMPOUND 148-62[47]

Base Elastomer - Silicone, Type - Dimethyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.	100 % Modulus psi	100 % Modulus % Chg.	Ultimate Elongation %	Ultimate Elongation % Chg.	Hardness Duro A	Hardness Chg.	Weight Change mg.	Rating
As-cured		0	409		232		143		54			
1. γ, Vac. 16 hrs., 70 F	1A	5.7×10^6	347	-15	289	+ 24	113	-21	55	+ 1	—	1
2. γ, Vac. 100 hrs., 70 F	2	6.2×10^7	315	-23	—	+ 76(3)	77	-46	65	+11	-2	4
3. γ, Vac.(4) 16 hrs., 70 F	11	6.4×10^6	331	-19	297	+ 28	110	-23	57	+ 3	-3	2
4. γ + UV, Vac.(2) 100 hrs., 335 F	7	6.1×10^7	71	-83	—	+206(3)	10	-93	68	+14	—	6
5. γ, Air 100 hrs., 70 F	5	2.4×10^7	329	-20	—	+ 77(3)	80	-44	60	+ 6	-5	3
6. γ, Air(4) 100 hrs., 70 F	6	3.8×10^7	321	-22	—	+106(3)	67	-53	64	+10	-3	5

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

(4) Combined radiation intended.

Table B-77. (Concluded)

<u>Time effect</u>: The radiation effects became more severe with increasing exposure time. This compound exhibited increasing cross-linking with exposure time.

<u>Atmosphere effect</u>: There was little difference between specimens exposed in air and vacuo. The specimens showed a slight weight loss for all conditions.

<u>Type irradiation effect</u>: The combined radiation was markedly more severe than straight gamma radiation for all properties compared in Conditions 2 and 4.

<u>Observation</u>: Condition 4, specimens darkened on face toward lamp. Two specimens broke in handling prior to test.

Table B-78. PHYSICAL PROPERTIES OF COMPOUND 149-62[47]

Base Elastomer - Silicone, Type - Dimethyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.[1]	100 % Modulus psi	100 % Modulus % Chg.[1]	Ultimate Elongation %	Ultimate Elongation % Chg.[1]	Hardness Duro A	Hardness Chg.[1]	Weight Change mg.	Rating
As-cured		0	266				90		64			
1. γ, Vac. 16 hrs., 70 F	1A	5.7×10^6	209	-21	—	- 3.4[3]	73	-19	70	+ 6	—	1
1' γ, Vac. 16 hrs., 70 F	3	7.8×10^6	21[illegible]	-18	—	+ 47[3]	50	-44	65	+ 1	- 3	3
2. γ, Vac. 100 hrs., 70 F	4	4.9×10^7	288	+ 8.3	—	+ 62[3]	60	-33	75	+11	- 2	3
3. γ + UV, Vac.[4] 16 hrs., 70 F	11	6.4×10^6	248	- 6.8	—	+ 39[3]	60	-33	70	+ 6	- 1	2
4. γ + UV, Vac.[2] 100 hrs., 335 F	7	6.1×10^7	136	-49	—	+130[3]	20	-78	79	+15	-12	6
5. γ, Air 100 hrs., 70 F	5	3.4×10^7	211	-21	—	+ 52[3]	47	-48	73	+ 9	+18	4
6. γ, Air[4] 100 hrs., 70 F	6	3.8×10^7	272	+ 2.2	—	+ 84[3]	50	-44	75	+11	+ 4	5

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Table E 73. (Concluded)

<u>Time effect</u>: Three canisters in this series had the same nominal gamma radiation for 16 hours in vacuo. Comparison of these showed the possibility of a "threshold" dosage required to start cross-linking since the exposure showing the tendency toward scission (decrease in modulus) had the lowest of the three recorded dosages. As the dosage increased, the apparent cross-linking increased.

<u>Atmosphere effect</u>: Examination of the effect of air and vacuo irradiation on mechanical properties did not show sufficient consistent differences to state that one was more severe than the other. The specimens gained weight in air and lost it in vacuo, the loss being greater in combined radiation than in straight gamma.

<u>Type irradiation effect</u>: Combined radiation produced more cross-linking effects than straight gamma in all properties compared in Conditions 2 and 4.

<u>Observations</u>: Condition 4, moderate to heavy browning on both faces of specimens, heaviest on face toward UV lamp.

TABLE B-79. PHYSICAL PROPERTIES OF COMPOUND 111-62[47]

Base Elastomer - Silicone, Type - Dimethyl Vinyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	1029		415		227		73			
1. γ, Vac. 16 hrs., 70 F	1A	5.7×10^6	1056	+ 2.6	584	+ 41	177	-22	74	+ 1	—	1
2. γ, Vac. 100 hrs., 70 F	2	6.2×10^7	816	-21	—	+318(3)	47	-79	87	+14	+4	4
3. γ, Vac.(4) 16 hrs., 70 F	11	6.4×10^6	809	-21	637	+ 54	130	-43	78	+ 5	+2	3
4. γ + UV, Vac.(2) 100 hrs., 335 F	7	6.1×10^7	302	-71	—	+628(3)	10	-96	88	+15	+3	6
5. γ, Air 100 hrs., 70 F	5	3.4×10^7	1151	+12	—	+340(3)	63	-72	—	+10	+4	4
6. γ, Air(4) 100 hrs., 70 F	6	3.8×10^7	1049	+ 1.9	—	+406(3)	50	-78	85	+12	+4	5
7. γ, Air 16 hrs., 70 F	1	7.5×10^6	1080	+ 4.9	699	+ 68	147	-35	75	+ 2	—	2

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Note: Continued on next page.

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TABLE B-79. (Continued)

<u>Time effect</u>: The cross-linking effect became more severe as exposure time increased. The threshold effect noted in other compounds was not apparent here.

<u>Atmosphere effect</u>: Effect of atmosphere was slight, but cross-linking was more predominant in the air exposures than in the vacuo exposures. A slight weight increase, almost identical for each group, was noted.

<u>Type irradiation effect</u>: Combined radiation produced more cross-linking than gamma radiation alone.

<u>Observation</u>: Condition 4, marked discoloration on face toward lamp.

TABLE B-80. PHYSIC L PROPERTIES OF COMPOUND 107-82(47)

Base Elast · .. ilicone, Type – Dimethyl Vinyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	859		523		150		64			
1. γ, Vac. 16 hrs., 70 F	1A	$5.{\cdot} \times 10^6$	932	+ 8.5	447	− 22	177	+18	66	+ 2	—	2
2. γ, Vac. 100 hrs., 70 F	2	6.2×10^7	655	−24	—	+213(3)	40	−73	80	+16	+1	6
3. γ, Vac.(4) 16 hrs., 70 F	11	6.4×10^6	796	− 7.3	565	+ 8.0	127	−15	66	+ 2	+2	1
4. γ + UV, Vac.(2) 100 hrs., 335 F	7	6.1×10^7	274	−62	—	+162(3)	20	−87	80	+1[illegible]	Nil	6
5. γ, Air 100 hrs., 70 F	5	3.4×10^7	926	+ 7.8	—	+164(3)	67	−55	75	+11	+3	4
6. γ, Air(4) 100 hrs., 70 F	3	3.8×10^7	760	−12	—	+191(3)	50	−67	78	+14	+4	5
7. γ, Air 16 hrs., 70 F	1	7.5×10^6	1001	+16	832	+ 59	123	−18	71	+ 7	—	3

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Note: Continued on next page.

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TABLE B-80. (Continued)

Time effect: Cross-linking increased as exposure time increased in both air and vacuo. The specimens exposed in vacuo apparently underwent scission during the 16 hour radiation period (Condition 1). A comparison of Conditions 1 and 3 showed a possible threshold value for cross-linking.

Atmosphere effect: After short-term radiation (16 hour), vacuum exposure showed predominant scission and air atmosphere resulted in cross-linking. After 100 hours, both showed predominant cross-linking with the effect more severe in vacuo than in air.

Type irradiation effect: The straight gamma radiation produced comparable or slightly greater effects on the properties.

Observation: Condition 4, heavy blackening on face toward UV lamp and moderate on back face.

TABLE B-81. PHYSICAL PROPERTIES OF COMPOUND 39-62[47]

Base Elastomer – Silicone, Type – Dimethyl Vinyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	731		449		210		67			
1. γ, Vac. 16 hrs., 70 F	3	7.8×10^6	703	- 3.8	626	+ 39	127	-39	72	+ 5	--	2
2. γ, Vac. 100 hrs., 70 F	4	4.9×10^7	787	+ 7.6	—	+150(3)	63	-70	73	+ 6	+4	4
3. γ + UV, Vac.(2) 16 hrs., 190 F	12	6.4×10^6	714	- 2.4	659	+ 47	113	-46	74	+ 7	-2	3
4. γ + UV, Vac.(2) 100 hrs., 250 F	10	6.1×10^7	1037	+42	—	+391(3)	47	-78	86	+19	Nil	6
5. γ, Air, 100 hrs., 70 F	8	4.1×10^7	838	+15	—	+196(3)	57	-63	81	+14	+2	4
6. γ + UV, Air(2) 100 hrs., 250 F	9	3.8×10^7	1027	+40	—	+332(3)	53	-75	83	+16	+1	5
7. γ, Air 16 hrs., 70 F	3	5.7×10^6	538	-26	455	+ 1.3	125	-40	69	+ 2	--	1

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

Note: Continued on next page.

TABLE 3-81. (Continued)

Time effect: The tensile was not affected greatly by time. The 100 per cent modulus markedly increased, hardness increased very slightly, and the ultimate elongation dropped as exposure time increased.

Atmosphere effect: The compound apparently reacted about the same in vacuo and in air. Weight changes were erratic within the groups and the net changes were insignificant.

Type irradiation effect: Cross linking was more severe for the combined irradiation than with the gamma radiation alone, as evidenced by the substantially larger increases in modulus, tensile strength, and hardness.

Observations. Condition 4, smoky discoloration—purple and green iridescent surfaces. Condition 6, smoked surfaces on face toward lamp. Condition 7, smoky discoloration in spots—purple iridescence.

TABLE B-32. PHYSICAL PROPERTIES OF COMPOUND 109-62(47)

Base Elastomer – Silicone, Type – Methyl Phenyl Vinyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	1473		229		500		62			
1. γ, Vac. 16 hrs., 70 F	1A	5.7×10^6	1591	+ 8.0	255	+ 11	445	-11	58	- 4	—	1
2. γ, Vac. 100 hrs., 70 F	2	6.2×10^7	774	-48	—	+404(3)	67	-87	78	+16	+3	6
3. γ, Vac.(4) 16 hrs., 70 F	11	6.4×10^6	1492	+ 1.3	304	+ 33	403	-19	57	- 5	+1	2
4. γ, Vac.(2) 100 hrs., 335 F	7	6.1×10^7	281	-80	—	+622(3)	17	-97	82	+20	Nil	7
5. γ, Air 100 hrs., 70 F	5	3.4×10^7	902	-32	—	+337(3)	90	-82	76	+14	+3	4
6. γ, Air(4) 100 hrs., 70 F	6	3.8×10^7	627	-57	—	+334(3)	63	-87	77	+15	+5	5
7. γ, Air 16 hrs., 70 F	[illegible]	7.5×10^6	1514	+ 2.7	347	+ 52	380	-34	62	Nil	—	3

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Note: Continued on next page.

Note: Continued on next page.

TABLE B-82. (Continued)

<u>Time effect</u>: The effects became markedly more severe as the exposure time was increased. This was true in both air and vacuo. The short-term exposures in vacuo showed a small drop in hardness coupled with slight increases in modulus and decreases in ultimate elongation, suggesting a balanced cross-linking-scission effect or a "threshold dose".

<u>Atmosphere effect</u>: At 16 hours the effect of gamma radiation in air was somewhat more severe than in vacuo. There were slight increases in weight in air indicating a small amount of oxidation.

<u>Type irradiation effect</u>: The combined radiation produced more cross-linking than gamma radiation alone, as evidenced by comparison of Conditions 2 and 4.

<u>Observation</u>: Condition 4, specimens blackened on face toward lamp. Darkened on opposite face.

TABLE B-83. PHYSICAL PROPERTIES OF COMPOUND 56-62[47]

Base Elastomer - Silicone, Type - Dimethyl Phenyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	1169		208		403		50			
1. γ, Vac. 16 hrs., 70 F	1A	5.7×10^6	899	-23	285	+ 37	227	-44	55	+ 5	---	1
2. γ, Vac. 100 hrs., 70 F	2	6.2×10^7	660	-41	---	+323(3)	75	-82	76	+26	Nil	5
3. γ, Vac.(4) 16 hrs., 70 F	13	6.4×10^6	938	-20	334	+ 60	220	-46	57	+ 7	+ 2	2
4. γ + UV, Vac.(2) 100 hrs., 335 F	7	6.1×10^7	270	-77	---	+464(3)	23	-94	80	+30	Nil	6
5. γ, Air 100 hrs., 70 F	5	3.4×10^7	692	-41	737	+254	93	-77	67	[illegible]	+ 6	3
6. γ, Air(4) 100 hrs., 70 F	6	3.8×10^7	429	-63	---	+289(3)	53	-84	76	+26	+17	4
7. γ, Air 16 hrs., 70 F	1	7.5×10^6	1069	- 8.6	368	+ 77	240	-41	56	+ 6	---	2

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Note: Continued on next page.

TABLE B-83. (Continued)

<u>Time effect</u>: All properties were time dependent for a given irradiation condition, with the changes being significant even for the shorter time.

<u>Atmosphere effect</u>: Cross-linking was less in air than in vacuo, but still the predominant effect. Specimens exposed to air gained some weight while those exposed in vacuo showed no change indicating a minor oxidative reaction in the air exposures.

<u>Type irradiation effect</u>: Combined radiation appeared to be more severe than straight gamma radiation.

<u>Observations</u>: Condition 2, tear strength noticeably decreased. Condition 4, blackened on face toward UV lamp.

TABLE B-84. PHYSICAL PROPERTIES OF COMPOUND 58-62(47)

Base Elastomer - Silicone Type - Dimethyl Phenyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	1147		117		383		53			
1. γ, Vac. 16 hrs., 70 F	1A	5.7×10^6	743	-35	301	+ 70	200	-49	55	+ 2	—	2
2. γ, Vac. 100 hrs., 70 F	2	6.2×10^7	777	-32	—	+456(3)	75	-81	76	+23	+2	5
3. γ, Vac.(4) 16 hrs., 70 F	11	6.4×10^6	550	-52	350	+ 98	143	-64	59	+ 6	+1	3
4. γ + UV, Vac.(2) 100 hrs., 335 F	7	6.1×10^7	202	-83	—	+470(3)	20	-95	77	+24	+1	7
5. γ, Air 100 hrs., 70 F	5	3.4×10^7	742	-35	—	+424(3)	80	-80	70	+17	+5	4
6. γ, Air(4) 100 hrs., 70 F	6	3.8×10^7	635	-45	—	+469(3)	63	-84	73	+20	+3	6
7. γ, Air 16 hrs., 70 F		7.5×10^6	1181	+ 3.0	359	+103	240	-39	56	+ 3	—	1

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

(4) Combined radiation intended.

Note: Continued on next page.

TABLE B-84. (Continued)

<u>Time effect</u>: Increase in exposure time produced marked effects on modulus, ultimate elongation, and hardness, and a somewhat irregular effect on tensile strength in both air and vacuo.

<u>Atmosphere effect</u>: Reaction was predominantly cross-linking whether specimens were exposed in air or vacuo. Weight changes were small and erratic.

<u>Type irradiation effect</u>: There was greater loss of tensile strength and slightly greater loss of elongation during combined radiation than during straight gamma radiation with other property changes being comparable.

<u>Observation</u>: Condition 4, specimens blackened on face toward UV lamp.

TABLE B-35. PHYSICAL PROPERTIES OF COMPOUND 110-62[47]

Base Elastomer – Silicone, Type – Methyl Trifluoro Propyl

Nominal Irradiated Condition	Can No.	Gamma Dose r.	Tensile Strength psi	Tensile Strength % Chg.(1)	100 % Modulus psi	100 % Modulus % Chg.(1)	Ultimate Elongation %	Ultimate Elongation % Chg.(1)	Hardness Duro A	Hardness Chg.(1)	Weight Change mg.	Rating
As-cured		0	1346		371		243		62			
1. γ, Vac. 16 hrs., 70 F	1A	5.7×10^6	591	-56	333	- 10	153	-37	62	Nil	—	2
2. γ, Vac. 100 hrs., 70 F	2	6.2×10^7	382	-72	—	+ 54(3)	67	-72	72	+10	- 8	4
3. γ + UV, Vac.(2) 16 hrs., 190 F	12	6.4×10^6	333	-75	—	+ 3(3)	87	-64	65	+ 3	- 4	3
4. γ + UV, Vac.(2) 100 hrs., 250 F	10	6.1×10^7	304	-77	—	+310(3)	20	-92	78	+16	-21	6
5. γ, Air 100 hrs., 70 F	8	4.1×10^7	374	-72	—	+ 50(3)	67	-72	73	+11	- 8	4
6. γ + UV, Air(2) 100 hrs., 250 F	9	3.8×10^7	372	-72	—	+203(3)	33	-86	74	+12	- 5	5
7. γ, Air 16 hrs., 70 F	1	7.5×10^6	988	-27	454	+ 22	180	-25	64	+ 2	—	1

(1) From as-cured value.

(2) Measured temperatures are uncertain.

(3) Value found by extrapolation.

Note: Continued on next page.

TABLE B-88. (Continued)

Time effect: The radiation effects increased with exposure time. Short-term radiation in vacuo showed scission effects. Otherwise the reaction was predominantly cross-linking. This indicated a threshold radiation for cross-linking.

Atmosphere effect: As noted above, short-term vacuo exposure showed effect of scission as opposed to cross-linking in air; otherwise, little difference due to atmosphere was noted. The specimens all lost weight and the effect was greatest on the specimens exposed to combined radiation in vacuo.

Type irradiation effect: Combined radiation appeared to cause more cross-linking than straight gamma radiation in the three comparisons (1 and 3, 2 and 4, and 5 and 6).

Observations: Condition 4, blackened on face toward lamp. Darkened on other face. Condition 6, moderate darkening on face toward lamp. Condition 7, sooty deposits on specimens.

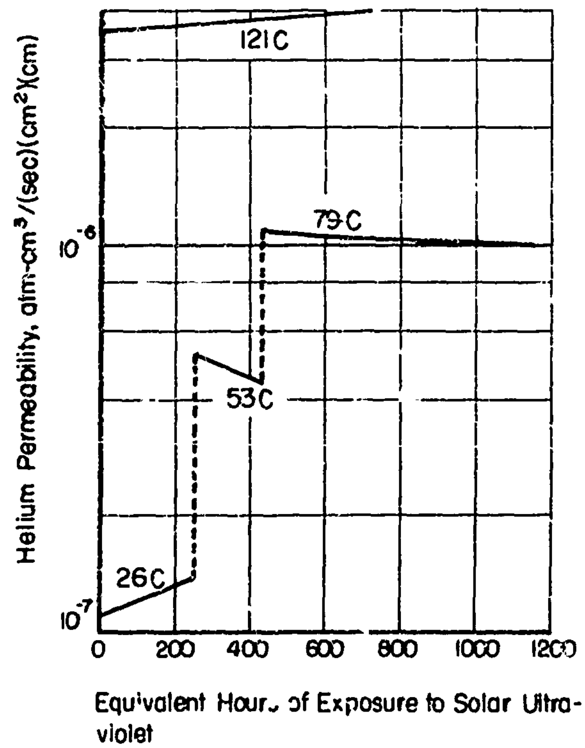

FIGURE B-1. CHANGE IN PERMEABILITY ON EXPOSURE TO ULTRAVIOLET RADIATION AT VARIOUS TEMPERATURE LEVELS - VITON "A"(4)

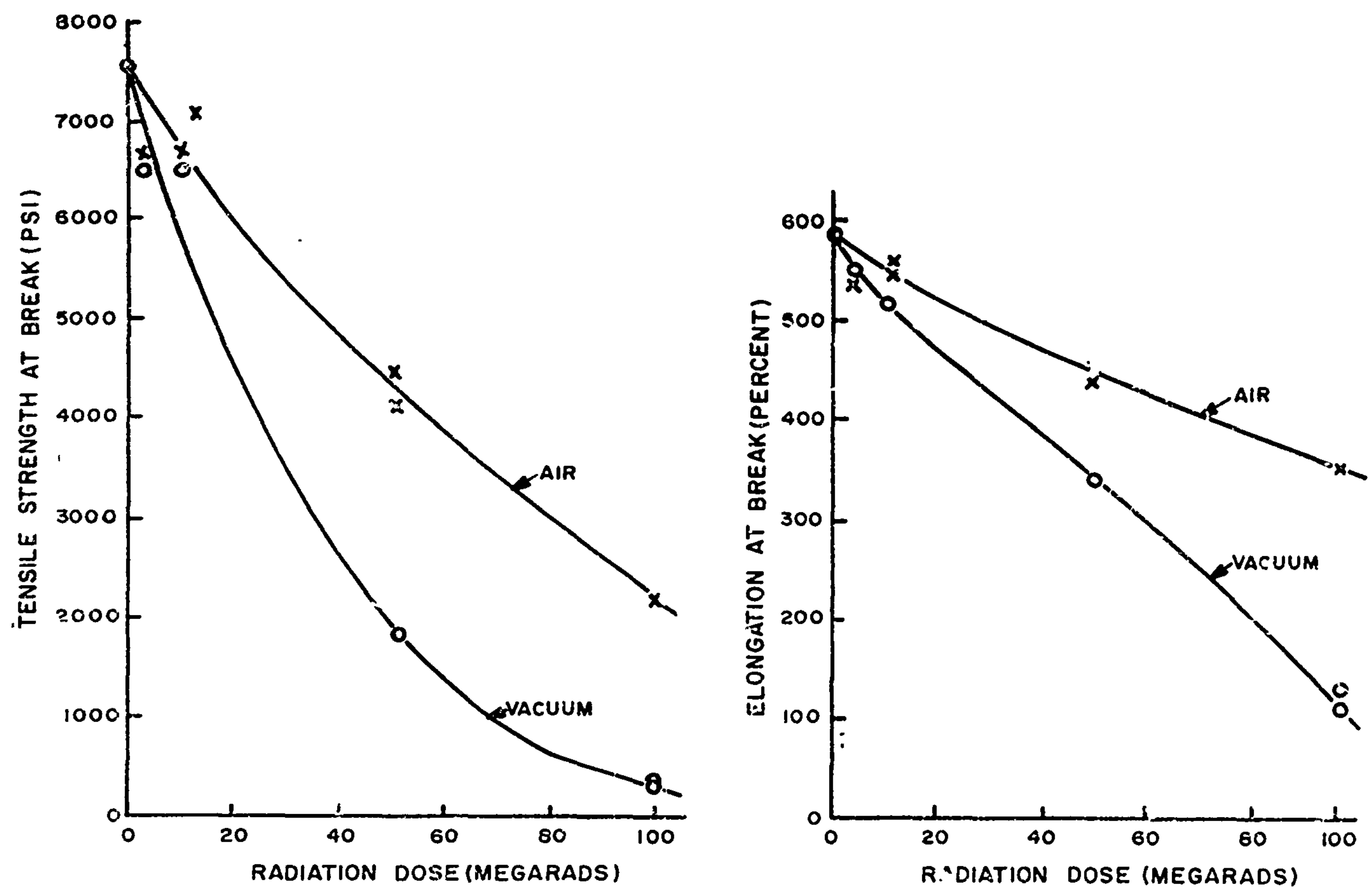

FIGURE B-2. TENSILE STRENGTH AND ELONGATION FOR POLYURETHANE IRRADIATED IN VACUUM AND IN AIR(18)

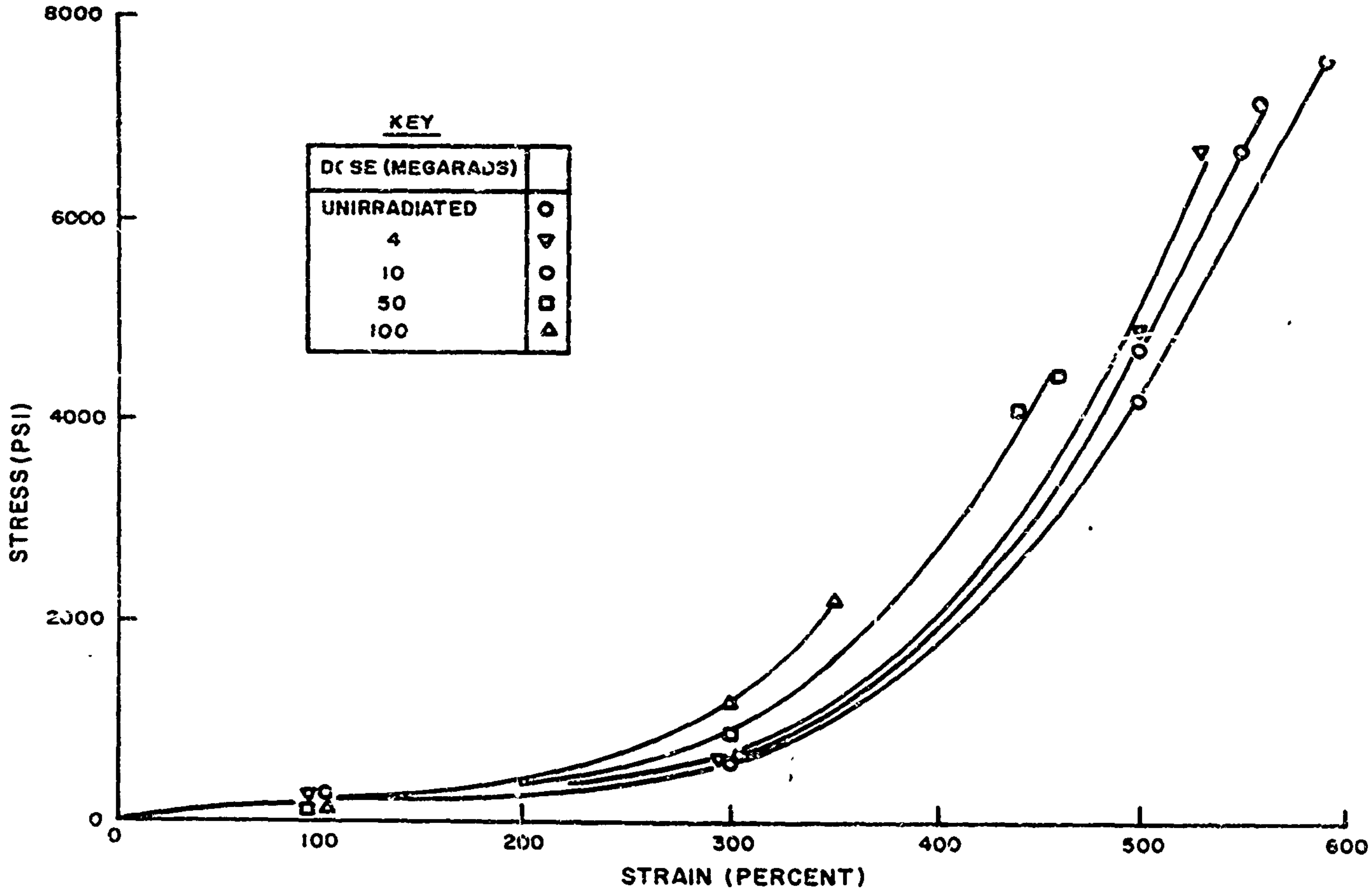

FIGURE B-3. STRESS/STRAIN CURVES FOR POLYURETHANE IRRADIATED IN AIR(50)

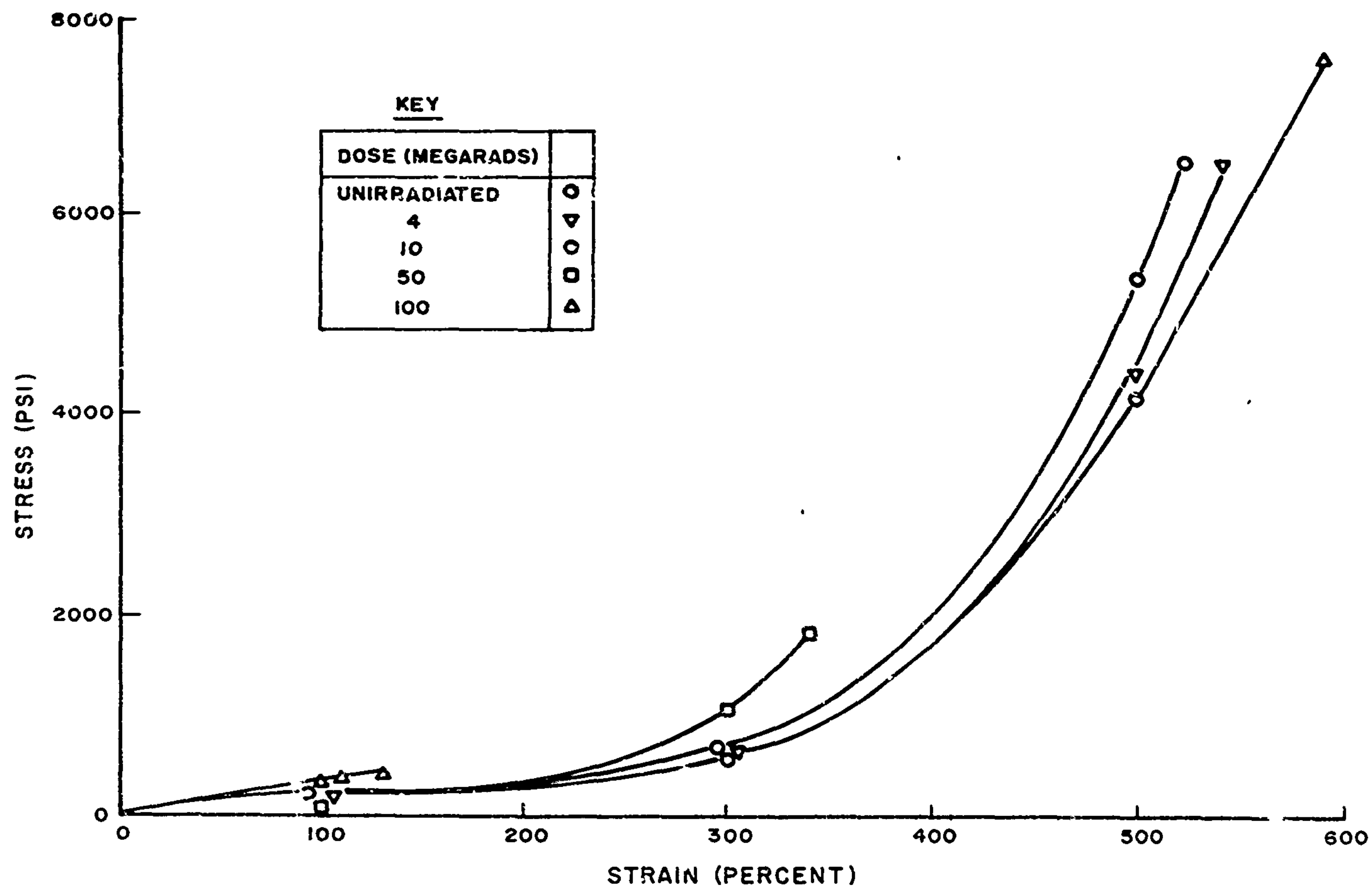

FIGURE B-4. STRESS/STRAIN CURVES FOR POLYURE HANE IRRADIATED IN VACUUM(50)

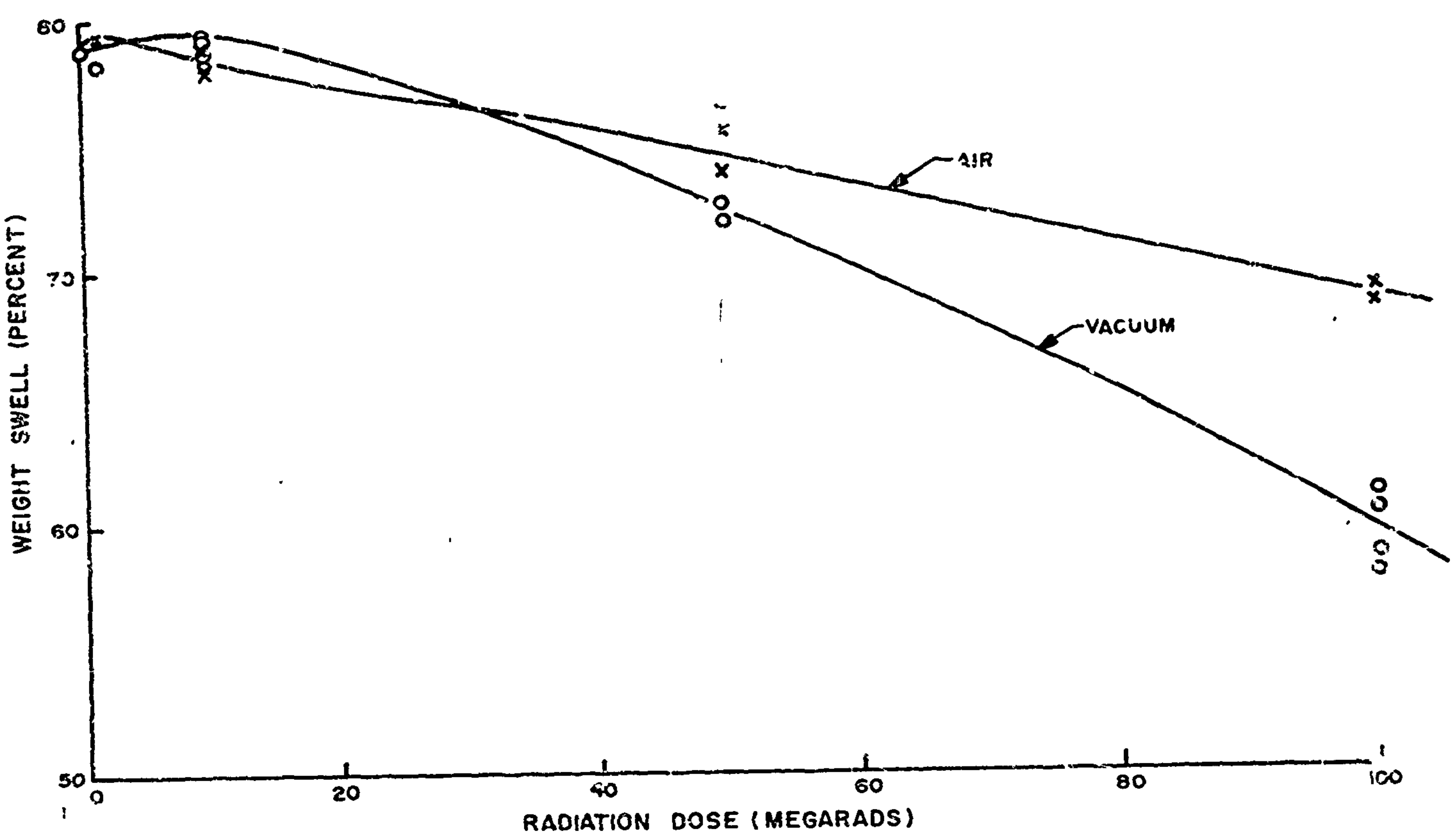

FIGURE B-5. SWELLING OF IRRADIATED POLYURETHANE SPECIMENS IN BENZENE[50]

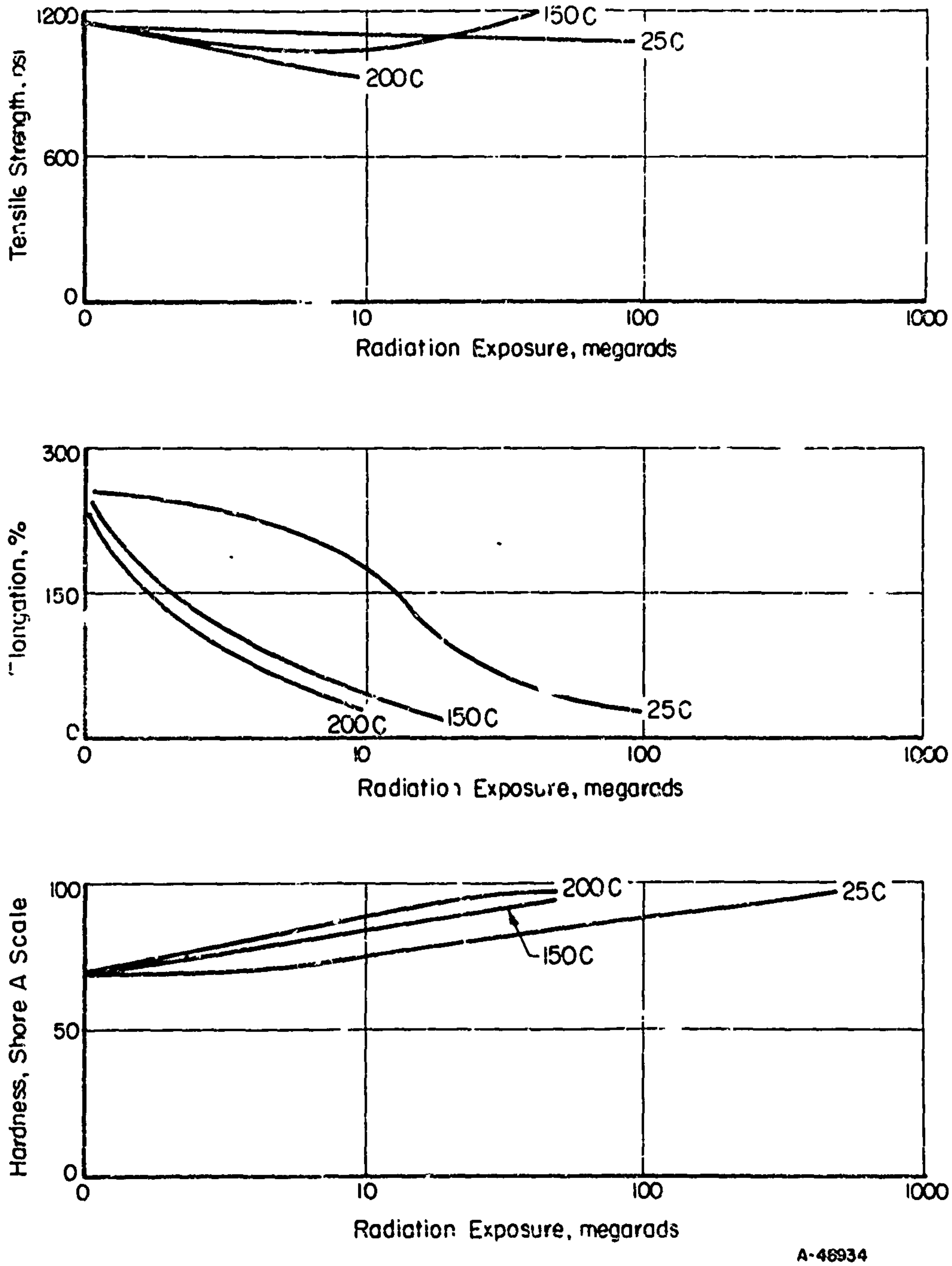

FIGURE B-6. EFFECTS OF GAMMA RADIATION ON PHYSICAL PROPERTIES OF SILASTIC 1602(36)

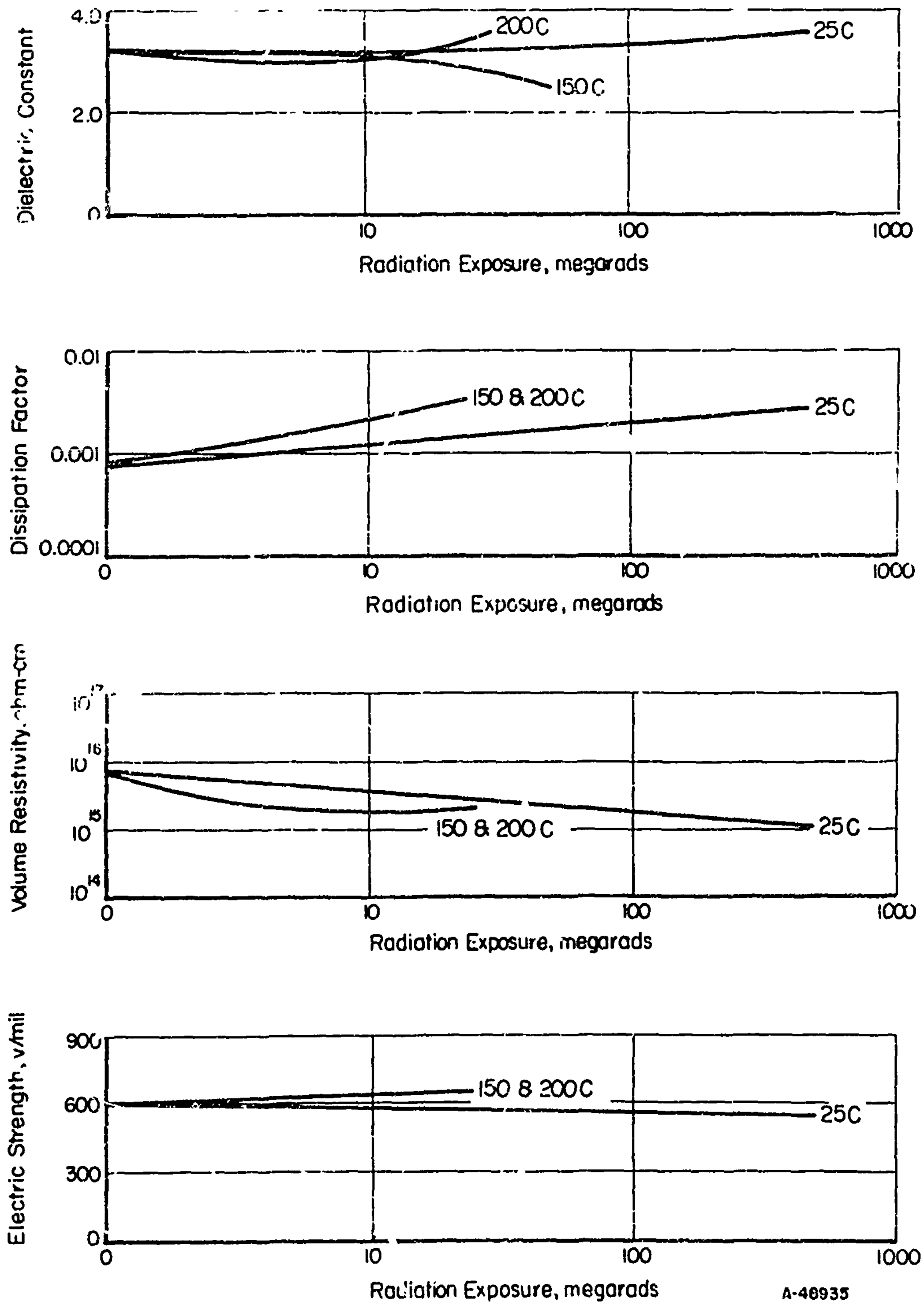

FIGURE B-7. EFFECTS OF GAMMA RADIATION ON ELECTRICAL PROPERTIES OF SILASTIC 1602[36]

APPENDIX C

PLASTICS

TABLE C-1. EFFECT OF ULTRAVIOLET ON PLASTICS(55)

Plastics	Radiation Wavelength Band, Å	Equivalent Insolation, hours: 1300 to 1850 Å	Equivalent Insolation, hours: 1100 to 1300 Å	Change of Appearance	Weight Loss, %	Quantum Yield, η %	Mass of Released Material
Butyl Compound B-26	1100-1850	123	3600	None	0.14	0.16	N.M.
Epoxy Resin (Epon 828)	1100-1850	37	780	None	0.10	0.15	N.M.
Polyester (Mylar A)	1100-1850	50	565	None	0.2± 0.2	0.15	28
Polyester (Mylar A)	2000-4000	—	—	None	0.3± 0.3	—	23
Polyethylene (Polyfilm 601)	1100-1850	28	1975	None	0	0.27	N.M.
Polymethyl Methacrylate (Plexiglas "G") Rubbed with cotton	1100-1850	204	645	None	0.13	0.12	N.M.
Polymethyl Methacrylate (Plexiglas "G") No masking paper	1100-1850	66	186	None	0.04	0	N.M.
Polymethyl Methacrylate (Plexiglas "G") No masking paper	1100-1850	150	2200	None	0.5	0.65	28
	2000-4000	—	—	None	0.5	—	28
Polystyrene (Trycite-1000)	1100-1850	128	3500	None	0.1±0.1	0	N.M.
Polystyrene (Trycite-1000)	1100-1850	29	[illegible]	None	-0.2±0.2	0	N.M.
Polyvinyl Chloride	1100-1850	130	1000	Yellow discoloration	0	0	N.M.
Polyvinyl Chloride	1100-1850	120	2140	Yellow discoloration	0	0	Not observed
Polyvinyl Chloride	1100-1850	120	2140	Yellow discoloration	0	0	Not observed

TABLE C-2. PHYSICAL PROPERTIES OF ACRILAN IRRADIATED IN NITROGEN WITH MONOCHROMATIC LIGHT[58]

Incident Energy, joules/cm^2	Wavelength, mμ	Tensile Strength, 10^3 psi	Young's Modulus, 10^5 psi	Elongation, per cent
0	-	33.4	3.97	24
179	369	34.3	3.18	20
1269	369	36.0	3.37	36
2200	369	34.6	4.49	18
5644	369	33.8	3.06	48
1082	314	34.0	1.12	38
58	244	36.0	-	33
193	244	31.5	0.82	30
225	244	34.6	1.45	11.5
649	244	18.6	2.83	14

TABLE C-3. PHYSICAL PROPERTIES OF ACRILAN IRRADIATED WITH G30T8 LAMP[58]

Irradiation Time, hours	Tensile Strength, 10^3 psi	Young's Modulus, 10^5 psi	Elongation, per cent
A. Irradiated in Nitrogen			
0	33.8	3.97	24
24	35.4	3.51	24
90	25.4	-	16
162	23.7	3.85	19
B. Irradiated in a Vacuum			
5	31.7	2.30	30
67	29.9	1.92	28
91	29.0	3.78	18
149	27.0	4.42	18

Table C-4. SUMMARY OF EQUILIBRIUM WEIGHT LOSS DATA[4]

Material	Temperature (C)	Pressure (torr)	Equilibrium Weight Loss Rate ($gm/cm^2/sec \times 10^{10}$)
Phenolic	121	760	ND
	121	9.5×10^{-1}	0.4
	121	2.2×10^{-2}	0.9
	177	760	56.1
	177	9.5×10^{-1}	16.0
	177	4×10^{-2}	15.3
	177	10^{-5}	15.0
	204	760	30.1
	204	9.5×10^{-1}	8.6
	204	4.6×10^{-2}	6.5
	204	1.2×10^{-5}	6.5
Epoxy	121	760	ND
	121	9.5×10^{-1}	1.1
	121	7×10^{-2}	1.0
	177	760	11.4
	177	9.5×10^{-1}	4.7
	177	4×10^{-2}	5.0
	177	10^{-5}	4.3
	204	760	97
	204	9.5×10^{-1}	25
	204	3.6×10^{-2}	20
	204	10^{-5}	19
Teflon	149	760	ND
	204	760	ND
	204	9.5×10^{-1}	0.2
Diallyl Phthalate	149	760	12.1
	149	9.5×10^{-1}	3.5
	149	2.3×10^{-2}	2.0
	149	10^{-5}	1.1
	177	760	20.9
	177	9.5×10^{-1}	6.6
	177	1.6×10^{-2}	12.1
	177	10^{-5}	7.7
Mylar	149	760	ND
	149	10^{-5}	ND
Silicone	177	760	3.9
	177	9.5×10^{-1}	2
	177	4×10^{-2}	0.9
	177	10^{-5}	ND

TABLE C-4. (Continued)

Material	Temperature (C)	Pressure (torr)	Equilibrium Weight Loss Rate ($gm/cm^2/sec \times 10^{10}$)
	204	760	46.8
	204	9.5×10^{-1}	9.6
	204	1.6×10^{-2}	3.5
	204	10^{-5}	7.3
	232	760	74.8
	232	9.5×10^{-1}	11.3
	232	6.0×10^{-2}	7.2
	232	10^{-5}	5.7
Viton A	177	10^{-5}	20
Irradiated polyolefin	50	5×10^{-6}	0.13-0.20
Wire insulation N)102E	100		18-2.3
Irradiated polyolefin shrinkable	50	5×10^{-6}	0.18
Tubing type RNF [illegible] 201	100	5×10^{-6}	1.1
Nylon (ZYTEL 105)	50	5×10^{-6}	[illegible]
	100	5×10^{-6}	[illegible]
Epiall 1288 molding	50	5×10^{-6}	0.44
Compound	100	5×10^{-6}	18
Irradiated polyolefin	50		0.472
Experimental type	100		22-23
Delrin 500	50	5×10^{-6}	0.56
	100		5.5
Epiall 1459 epoxy	50	5×10^{-6}	0.72
Molding compound	100		1.31
Nylon (ZYTEL 31)	50	5×10^{-6}	0.89
	100		[illegible]
Nylon (ZYTEL 101)	50		0.94
	100		4.2
Delrin 507	50	5×10^{-6}	1.4
	100		4.4

TABLE C-4. (Concluded)

Material	Temperature (C)	Pressure (torr)	Equilibrium Weight Loss Rate (gm/cm^2/sec x 10^{10})
DAP type 3-2-530	50 100	5 x 10^{-6}	1.75 3.34
DAP type 52-01	50 100	5 x 10^{-6} 5 x 10^{-6}	2 4.4
DAP type 1-530	50 100	5 x 10^{-6}	2.2 3.3
DAP type 1-503	50 100	5 x 10^{-6}	2.3 3.06
Devcon F epoxy	50	5 x 10^{-6}	2.5
Room temperature cure	100		5
DAP Type FS-5	50 100		4.2 3.1
Armstrong epoxy	50		10.6
Room temperature cure	100		17.8
Phenolic laminate	50		10.3-12.2
Grade XX natural	100		24.8
Phenolic laminate	50	5 x 10^{-6}	10.8-11.7
Grade LB 103	100		8.9-9.5
Phenolic laminate	50		13.3-14.4
Grade LBB natural	100		10.6-12
Epiall 1552	100	5 x 10^{-6}	12.6
Molding compound			

TABLE C-5. WEIGHT LOSS IN VACUUM OF DIALLYL PHTHALATE, PRESSURE <5 x 10^{-6} MM Hg(17)

Material	Composition	Total Weight Loss to Stationary State, g/cm²		Time to Stationary State, hours		Stationary State Weight Loss Rate, g/cm²/hour	
		50 C	100 C	50 C	100 C	50 C	100 C
FS-5	Meta form, short-glass-fiber filled	2.6 x 10^{-4}	6.5 x 10^{-4}	55	88	1.5 x 10^{-6}	1.1 x 10^{-6}
3-2-530	Meta form long-glass-fiber filled	1.1 x 10^{-4}	4.2 x 10^{-4}	55	88	6.3 x 10^{-7}	1.2 x 10^{-6}
52-01	Ortho form, short-glass-fiber filled	1.3 x 10^{-4}	3.1 x 10^{-4}	55	64	7.3 x 10^{-7}	1.6 x 10^{-6}
1-530	Ortho form, long-glass-fiber filled	1.0 x 10^{-4}	4.1 x 10^{-6}	55	64	3.0 x 10^{-7}	1.2 x 10^{-6}
1-503	Ortho form, orlon filled	1.2 x 10^{-4}	5.1 x 10^{-4}	55	88	8.4 x 10^{-7}	1.1 x 10^{-6}

TABLE C-6. FLUOROCARBON PLASTICS – COMPARATIVE PROPERTIES(64)

Property	PTFE	PFEP	PCTFE
Crystalline Melting Point, C	327	285	220
Specific Gravity	2.13-2.20	2.14-2.17	2.10-2.16
Tensile Strength, psi	1500-3000	1500-3000	4500-5500
Elongation, per cent	150-450	250-330	100-175
Compressive Strength, psi			
at 0.2% offset	-	-	5500
at 1.0% offset	600	-	7850
at 2.0% offset	-	1400	8400
Coefficient of Friction against steel	0.04	0.08	0.43
Hardness, Shore D	65	55	80
Dielectric Constant	2.10	2.10	2.59
Dissipation Factor (1000 cps)	<0.0002	<0.0002	0.0215
Moisture Absorption, per cent	0	0	0
Water Vapor Transmission Rate 10 mil film, 100% R.H. at 25 C, gms/100 in^2/24 hrs/mil	-	0.310	0.030
Maximum Recommended Service Temperature, F	500	400	390
Chemical Resistance	Inert to most chemicals and solvents with the exception of alkali metals. Halogenated solvents at high temperatures and pressure have some effect.	Impervious to corrosive chemicals; nighly resistent to most organic solvents. Swelling may occur with some highly halogenated and aromatic compounds.	...ghly ... with ...lated ...unds.

TABLE C-7. FLUOROCARBON POLYMERS – TENSILE PROPERTIES(a) OF TEFLON 100 FEP AND REINFORCED TEFLON VERSUS IRRADIATION AND MIXED ENVIRONMENTS(48)

Integrated Neutron Flux (N), n cm^{-2} (E >0.33)(b) Gamma Exposure (G), ergs g^{-1} (C)(b)	Teflon 100 FEP(c)				Reinforced Teflon(c)
	.021 In. Thick		0.115 In. Thick		.030 In. Thick
	Ultimate, psi	Ultimate Elongation, %	Ultimate, psi	Ultimate Elongation, %	Ultimate, psi
Controls	2609/8.5/14	328/5.2/9	2144/8 /10	280/7.6/8	25,303/13 /7
N 6.3×10^{13} G 1×10^{8}			1883/6.9/10	235/12 /8	20,458/9.5/8
N 2×10^{14} G 2.5×10^{8}	1839/2.4/10	220/12 /10	1808/3 /10	172/13 /10	20,264/14 /9
N G 2.8×10^{8}					
N 2.5×10^{14} G 4.8×10^{8}	1675/0.5/5	Not brittle			
N 1.1×10^{15} G 7.4×10^{8}	1662/1.1/5	Not brittle			
N 7.9×10^{15} G 1.2×10^{10}		Brittle		Brittle	10,767/29 /6 (not brittle)

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.
(b) Ambient irradiation temperature.
(c) Test temperature 80 F.

TABLE C-8. FLUOROCARBON POLYMERS – TENSILE PROPERTIES(a) OF TEFLON TFE VERSUS IRRADIATION AND MIXED ENVIRONMENTS(43)

Integrated Neutron Flux (N), n cm^{-2} (E >0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation Temp, F	Teflon TFE(b) 0.010 In. Thick Air(c) Ultimate, psi	Teflon TFE(b) 0.010 In. Thick Oronite 8515(c) Ultimate, psi	Teflon TFE(b) 0.125 In. Thick Air(c) Ultimate, psi	Teflon TFE(b) 0.125 In. Thick Oronite 8515(c) Ultimate, psi
Control	80	2495/12 /20		2545/9.3/10	
N 1.5-1.7 x 10^{14} G 1.3-1.4 x 10^{8}					
	-65	1481/12 /20			
	80			1217/5.1/5	1229/1.2/5
	Ambient	1265/3.5/10	1452/5.2/10		
	275	1107/13 /5	1590/6 /10		
N 5.9-6.6 x 10^{14} G 0.8-1.0 x 10^{9}					
	80			118[illegible]/5.7/5	1333/1.[illegible]/5
	Ambient	888/15 /5	1396/4.6/9		
N 5.9-6.5 x 10^{15} G 1.3-1.5 x 10^{10}					
	80			832/12 /4	1302/6.2/5
	Ambient	No measurable strength	1641/6.4/6		

(a) Data are given as $\bar{x}$/S.D./n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

(c) Irradiation media.

TABLE C-9. FLUOROCARBON POLYMERS – TENSILE PROPERTIES(a) OF TEFLON TFE VERSUS IRRADIATION AND MIXED ENVIRONMENTS(48)

Integrated Neutron Flux (N), n cm^{-2} (E >0.33 Mev)(b) Gamma Exposure (G), ergs g^{-1} (C)	Teflon TFE(c) 0.0033 In. Thick Air(d) Ultimate, psi	0.011 In. Thick Air(d) Ultimate, psi	0.011 In. Thick Cronite 8515(d) Ultimate, psi	0.021 In. Thick Air(d) Ultimate, psi	0.021 In. Thick Helium(d) Ultimate, psi	0.041 In. Thick Air(d) Ultimate, psi	0.115 In. Thick Air(d) Ultimate, psi	0.115 In. Thick Helium(d) Ultimate, psi
Control	2717/13/10	2886/4.4/6		[illegible]503/7 /7		3040/6.7/10	3135/8.6/10	
N 2.8×10^{14} G 4.8×10^{8}	1096/21/6	1371/11 /10		1293/5.9/10		1197/2.2/8	1035/4.7/10	
N 4.5×10^{14} G 6.8×10^{8}	917/18/4	1128/16 /4		1171/7.5/19		1226/2.3/16	1356/2.1/19	
N 7×10^{14} G 1.2×10^{9}	Too brittle				1571/1.8/20	797/13 /6	867/12 /8	1545/4 /20
N 1.6×10^{15} G 2.3×10^{9}		1286/15 /5	1664/4.2/10					
N 5.7×10^{15} G 1.1×10^{10}		Too brittle		569/22 /4		591/16 /14	638/20 /10	
N 1×10^{16} G 1.7×10^{10}					1749/2.4/20			1311/13/19
N 1.5×10^{16} G 2.1×10^{10}			1490/13 /4					

(a) Data are given as $\bar{x}$/S.D. /n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Ambient irradiation temperature.

(c) Test temperature 80 F.

TABLE C-10. TENSILE PROPERTIES(a) OF POLYVINYL FLUORIDE FILM VERSUS IRRADIATION, TEMPERATURE, AND IMMERSION MEDIA(48)

Integrated Neutron Flux (N), n cm^{-2} (E >0.33 Mev) Gamma Exposure (G), ergs g^{-1} (C)	Irradiation Temp, F	Tedlar(b), 4 Mils Thick: Air(c) Breaking Strength, lb/in.	Air(c) Ultimate Elongation, %	MIL-808(c) Breaking Strength, lb/in.	MIL-808(c) Ultimate Elongation, %	Oronite 8515(c) Breaking Strength, lb/in.	Oronite 8515(c) Ultimate Elongation, %	JP4 Fuel(c) Breaking Strength, lb/in.	JP4 Fuel(c) Ultimate Elongation, %
Control	80	56.2/5 /10	74 /9.1/9	56.4/1.9/9	88 /7.7/9	53.4/4.4/10	81/11/9		
		52.3/5 /9	75.6/8.9/9	52.4/4.3/10	77.2/11 /9	52.8/5.2/8	79/11/8		
N 1.5-1.8 x 10^{14}	-65	45.9/2.4/10	72.2/9.4/9						
G 1.3-1.6 x 10^{8}	260	38.7/2.2/10	70.7/13 /7			49.3/4 /10	76/6.7/9		
N 0.9-1.1 x 10^{14}	80	48.5/8.4/9	80.6/11 /8	46.8/3.3/8	67 /11 /8				
G 1.3-1.5 x 10^{8}	260	51 /4.3/10	73 /5.4/6						
N 7.0-7.7 x 10^{14}	-65	44.8/6 /9	73 /12 /8			44.4/2.1/10	63/8 /10		
G 8.0-9.0 x 10^{8}	80	48.6/9.1/10	75 /21 /6	46.2/2.8/10	66 /11 /10				
	260			43.6/4.7/9	56 /6.2/9				
N 1.0-1.3 x 10^{15} G 1.2-1.3 x 10^{9}	260	34.8/1.5/9	95.6/13 /9			43.8/5.6/9	56/6.6/7		
N 5.0-8.0 x 10^{15}	-65	39.0/6.9/10	34 /14 /7						
G 1.0-1.4 x 10^{10}	80	37.4/7.3/10	36 /9.3/8	40. /10 /10	31 /21 /10	36.7/16 /8	33/12 /6	40.3/5/8	49/13/8
	260	27.5/8.8/8	23 /32 /7	30 /7.2/9	37.8/15 /8	22.1/11 /7	39/25 /6		
N 4.5 x 10^{15} G 7 x 10^{10}	80	17.4/20 /8	<5 / /3						

		Tedlar(b), 2 Mil Thick: Air(c) Breaking Strength, lb/in.	Air(c) Ultimate Elongation, %	Tedlar(b), Laminated 4-Mil Sheet = 0.100 in. Thick: Air(c) Ultimate Tensile, psi	Air(c) Ultimate Elongation, %	Oronite 8515(c) Ultimate Tensile, psi	Oronite 8515(c) Ultimate Elongation, %
Control	80	9.65/7.1/4	230/11 /4	5744/12/15	142/14/14		
N 5.0-8.0 x 10^{15}	80	4.9/24 /4	10/ /4				
G 1.0-1.4 x 10^{10}	260			4618/18/5	16/54/5	3874/4/12	26/47/11
N 4 x 10^{14} G 1 x 10^{14}	Ambient	8.9 / 9.8/4	115/1.1/4				

(a) Data are given as $\bar{x}$/S.D. /n, where $\bar{x}$ = average value, S.D. = standard deviation of individual observation estimated from the range, and n = number of specimens used in calculating $\bar{x}$ and S.D.

(b) Test temperature 80 F.

(c) Immersion media.

(c) Immersion media.

TABLE C-11. DESIGN FOR IRRADIATED TEFLON RESINS*[62]

	Radiation Dose,** $\times 10^8$ Ergs g^{-1}(C)	Elongation, per cent	Tensile Strength, psi	Dielectric Constant ($\pm$ 0.05)
Atmosphere	0	165	3000	2.1
Atmosphere	0.1	152	1882	2.1
Atmosphere	0.5	37	1539	2.1
Atmosphere	1.0	21	1388	2.1
Atmosphere	5.0	—	1322	2.1
Vacuum (10^{-6} mm Hg)	1.0	92	2481	2.1
Vacuum (10^{-6} mm Hg)	5.0	73	1972	2.1
Vacuum (10^{-6} mm Hg)	51.0	38	1462	2.1
Vacuum (10^{-6} mm Hg)	150.0	16	800	2.1

* These data also apply to Teflon FEP resin. Actual experimental data even indicate a slight improvement in the above characteristics for this material. Radiation source was Co^{60} isotope emitting gamma rays at 1.3 x 10^6 rads/hour. Temperature was 25 C (77 F). Sample was 0.010-inch film of a Teflon TFE resin. Note that values for tensile strengths and elongations are known to be conservative based on current techniques of end-product fabrication.

** Conversion factors useful for determining performance expectancies for other-than gamma radiation follow: 1 rad = 1.2 roentgens; 1 rad = 1 x 10^{10} thermal neutrons/cm^2 = 1 x 10^{10} Nvt; 1 rad = 2.8 x 10^8 fast neutrons/cm^2 (2 Mev); 1 rad = 1.4 x 10^9 gamma protons/cm^2 (2 Mev); 1 rad = 5.2 x 10^7 electrons/cm^2 (1 Mev).

TABLE C-12. TENTATIVE ASSIGNMENTS OF INFRA-RED PEAKS(82)

Infra-red Peak (cm^{-1}) Due to Irradiation in: Vacuum	Air	Tentative Assignment
--	3472	COOH
--	3096	COOH
--	1880 enhanced	
--	1757	COOH
1350	1350	Unsaturation?
981.8	983.7	Unsaturation?

TABLE C-13. LOW-FORCE DYNAMIC TEST RESULTS: RUN II, June 4, 1963(7)

Material Trade Name	Test Condition	Radiation Exposure: Gamma [ergs/gm(C)]	Radiation Exposure: Neutron (n/cm^2) Thermal	Neutron (n/cm^2) E>2.9 Mev	Neutron (n/cm^2) E>6.1 Mev	Tensile Strength[a] (psi): 25% Elongation	Tensile Strength[a] (psi): 50% Elongation	Tensile Strength[a] (psi): 100% Elongation	Tensile Strength[a] (psi): Ultimate	Ultimate Elongation, per cent	Temperature Avg. (F)	Pressure Avg. (torr)
Teflon TFE Film 10 mil	Vacuum Irradiation	5.08(8)	8.31(12)	6.98(13)	2.77(12)	2090 2160 2065 2105/56	2225 2180 2120 2175/62	2575 2350 2320 2415/151	2650 2460 2860 2657/236	109.1 114.2 159.3 127.529.7	87	2.5(-7)
						Flexural Strength: Maximum Fiber Stress (psi)	Flexural Strength: Maximum Fiber Strain in./in.	Flexural Strength: Modulus (psi)				
Kel-F-81	Vacuum Irradiation	5.08(8)	8.31(12)	6.98(13)	2.77(12)	12,278 9,300	0.092 0.076	135,679 137,070	--	--	--	--

(a) Values given as: average value/standard deviation on an individual basis.

(b) Figures showing plotted data to be presented and listed in the annual report.

TABLE C-14. TEST ENVIRONMENTS AND RESULTS OF STATIC TESTS(6,7)

Material Trade Name	Test Condition	Radiation Exposure: Gamma [ergs/gm(C)]	Neutron (n/cm²) Thermal	Neutron (n/cm²) >2.9 Mev	Neutron (n/cm²) >8.1 Mev	Time Until Test, days	Sample weight: Original, gm	Sample weight: Change, gm	Tensile Strength* (psi) at 25% Elongation	Tensile Strength* (psi) at 50% Elongation	Tensile Strength* (psi) at 100% Elongation	Tensile Strength* (psi) Ultimate	Ultimate Elongation, percent	Temperature Avg., (F)	Press. Avg., (torr)
Teflon TFE (10 mil)	Air	0	0 (control specimens)	0	0	—			1863 1909 1745 1681 1800/111	2109 2318 2036 2136 2150/137	2109 2590 2263 — 2381/161.4	3572 3845 3418 5363 4049/894.0	255 260 240 330 271/42.5	—	—
	Air	6.5(7)	3.5(12) (air irradiation)	1.4(13)	6.0(11)	11			— — — — — —	— — — — — —	— — — — — —	1772 1663 1709 1700 1772 1723/51.1	30 70 65 70 65 60/17.0	80	—
	Air	1.5(8)	3.?(12) (air irradiation)	3.0(13)	1.1(12)	11			— — — — — —	— — — — — —	— — — — — —	1690 1645 1709 1700 1672 1683/27.0	40 35 45 30 30 36/6.5	80	—
	Air	6.8(8)	2.4(13)	1.2(14)	4.9(12)	x			Too brittle to test						
	Air	7.?(7)	4.6(11) (vacuum irradiation)	5.2(12)	2.35(11)	9	2.229? 2.219? 2.3813 2.2462 2.2907	-0.0012 -0.0025 -0.0003 -0.0009 -0.0008	1772 1590 1727 1727 1681 1699/70	1999 1863 1909 1954 1954 1936/58	2181 2136 2136 2181 2227 2172/34.6	3272 3363 3272 3227 2318 3090/440	235 260 260 230 210 239/21.4	60	1.?(-7)
	Air	9.1(7)	? 8(12) (vacuum irradiation)	1.7(13)	7.0(11)	9	2.2188 2.1787 2.2885 2.1441 2.3858	+0.0003 +0.0003 -0.0001 +0.0008 0.0000	1636 1636 1545 1681 1545 1609/58	1909 1863 1772 1909 1818 1854/59	2090 2090 2045 2136 2090 2090/32.1	2863 2363 2818 2636 2727 2681/175	200 150 200 190 180 184/20.8	80	1.7(-7)
	Air	1.68(8)	1.7(12) (vacuum irradiation)	1.9(13)	—	10			1590 1772 1545 1636/134	1800 2136 1882 1969/151	2136 2363 2118 2206/142	3863 2909 2227 3000/822	190 180 120 163/39.4	85	2.3(-7)
	Air	4.45(8)	1.95(13) (vacuum irradiation)	5.45(13)	2.1(12)	10	2.2441 2.3956 2.2721 2.3678 2.3278	-0.0009 -0.0005 -0.00[illegible] -0.0[illegible] -0.0003	1590 1681 1727 172[illegible] [illegible] 16[illegible]	1654 1790 1818 1818 1745 1764/71	— — 2054 2027 1900 1997/77.2	1772 2136 2409 2209 2136 2132/228	60 125 140 134 143 120/34.5	90	4(-7)
	Air	5.03(8)	8.31(12) (vacuum irradiation)	6.96(13)	2.77(12)	9			1264 1336 1345 1315/48	1291 1336 1364 1330/43	— — — —	1409 1373 1418 1400/23.8	98 80 95 91/9.65	87	2.5(-7)

TABLE C-14. (Continued)

Material Trade Name	Test Condition	Gamma (ergs/gm(C))	Radiation Exposure: Neutron (n/cm²) Thermal	>2.9 Mev	>8.1 Mev	Time Until Test, days	Sample Weight Original gm	Sample Weight Change gm	Tensile Strength* (psi) at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Ultimate Elongation, percent	Temperature Avg. (F)	Press. Avg. (torr)
Teflon TFE (40 mil) Die A specimen	Air	0	0 (control specimens)	0	0	—			2014	2108	2249	2905	400	—	—
									1848	1971	2061	2786	275		
									1988	2120	23[illegible]	2833	275		
									1864	1978	20[illegible]	2796	300		
									1929/81	2044/72	2177/[illegible]	2830/58	313/61		
	Air	1.5(8)	3.3(12) (air irradiation)	3.0(13)	1.1(12)	13			—	—	—	[illegible]	1	80	--
									—	—	—	1701	1		
									—	—	—	1847	1		
									—	—	—	[illegible]	1		
									—	—	—	[illegible]	1		
									—	—	—	1806/129	1/0		
	Air	6.6(8)	2.40(13) (air irradiation)	1.2(14)	4.9(12)	13			—	—	—	364	1	82	—
									—	—	—	381	1		
									—	—	—	402	1		
									—	—	—	742	1		
									—	—	—	70[illegible]	1		
									—	—	—	519/163	1/0		
	Air	9.1(7)	7.8(12) (vacuum irradiation)	1.7(13)	7.0(11)	6	5.8602	-0.0001	1762	—	—	1762	65	80	1.7(-7)
							5.8667	-0.0003	1772	—	—	1772	25		
							5.8500	-0.0004	—	—	—	1493	45		
							5.8583	-0.0004	1607	1539	—	1539	50		
									1714/97	—	—	1642/136	46/19		
	Air	3.9(9)	1.9(13) (vacuum irradiation)	4.4(13)	1.7(12)	10	5.8218	+0.0003	—	—	—	1773	15	90	[illegible](-7)
							5.8271	-0.0006	—	—	—	1772	22		
							5.7846	-0.0007	—	—	—	1830	45		
							5.8157	-0.0003	—	—	—	1816	20		
							5.7941	-0.0007	1742	—	—	1798	25		
									1742	—	—	1798/25	25/13		
Teflon FEP (10 mil)	Air	0	0 (control specimens)	0	0	—			1970	2040	2080	—	—	—	—
									2040	2120	2150	—	—		
									2000	2050	2140	—	—		
									2180	2280	2340	3480	310		
									2000	2070	2120	—	—		
									1910	2050	2100	3830	367		
									2000	2060	2120	3580	325		
									1970	2060	2100	3800	363		
									2010	2090	2140	3700	323		
									2000	2050	2110	4100	381		
									2000	2070	—	3680	350		
									2000	2070	2120	3860	369		
									2020	2110	2150	3760	360		
									[illegible]	2100	2150	3910	372		
									[illegible]	2087/68	2140/78	3770/201	357/23		

TABLE C-14. (Continued)

Material Trade Name	Test Condition	Radiation Exposure: Gamma (ergs/gm(C))	Neutron (n/cm²): Thermal	Neutron (n/cm²): E>2.9 Mev	Neutron (n/cm²): E>8.1 Mev	Time Until Test, days	Sample Weight: Original, gm	Sample Weight: Change, gm	Tensile Strength[a] (psi): at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Ultimate Elongation, percent	Temperature Avg., (F)	Press. Avg., (torr)
	Air	6.5(7)	3.5(12) (air irradiation)	1.4(13)	6.0(11)	16			2000	2000	2130	2420	250	80	—
									2000	2100	2130	3550	370		
									2000	2070	2130	2800	300		
									2050	2100	2150	2300	240		
									2013/24	2088/25	2135/10	2768/607	290/63		
	Air	6.8(8)	2.4(13) (air irradiation)	1.2(14)	4.9(12)	16			2000	2040	2030	2300	140	82	--
									1950	2000	2000	[illegible]	220		
									1950	2000	1970	[illegible]	210		
									1960	1950	1940	[illegible]	[illegible]		
									1950/49	1998/44	1985/38.4	2245/49.4	177.5/43.5		
	Air	7.5(7)	4.8(12) (vacuum irradiation)	5.2(12)	2.35(11)	9	2.1568	-0.0104	2050	2100	2160	3800	365	60	1.7(-7)
							2.1449	-0.0001	2050	2100	2160	4020	4 0		
							2.1317	-0.0037	2030	2100	2150	3780	380		
							2.1663	+0.0003	2050	2100	2150	3830	365		
							2.1632	-0.0009	2070	2150	2200	3570	345		
									2050/17	2110/21	2160/21.1	3820/127.5	337/30.0		
	Air	1.8(9)	8.4(12) (vacuum irradiation)	1.85(13)	7.6(11)	9	2.1571	0.0000	2000	2100	--	[illegible]	[illegible]		1.7(-7)
							2.1834	-0.0083	2000	2070	2150	3050	320		
							2.1576	-0.0032	2100	2150	--	3830	395		
							2.1908	-0.0017	1800	1870	1950	3300	330		
							2.1562	-0.0081	1800	1850	1950	--	--		
									1940/129	2050/129	2017/117.0	3445/336.2	349.5/34.2		
	Air	4.45(8)	1.95(13) (vacuum irradiation)	5.45(13)	2.1(12)	10	2.1542	+0.0021	1960	2010	2070	2230	270	90	4(-7)
							2.1530	+0.0015	1950	1990	2060	2400	280		
							2.1480	+0.0013	1960	2030	2060	3000	--		
							2.2139	-0.0023	2000	2050	2120	2320	275		
							2.1410	-0.0108	1940	1970	--	2260	275		
									1952/26	2010/34	2077.5/25.0	2442/322.0	275/4.1		
Teflon FEP (40 mil) Die A Specimen	Air	0	0 (control specimens)	0	0	-			1860	1906	1930	2930	385		
									1985	2009	2009	2583	325		
									1886	1910	1933	2641	345		
									1983	1932	1932	2704	350		
									1915	1943	1971	2728	330		
									[illegible]	[illegible]	1955/34	2717/149	347/26		
	Air	1.5(8)	3.3(12) (air irradiation)	3.0(13)	1.1(12)	16			[illegible]	[illegible]	[illegible]	2102	300	80	--
									[illegible]	1835	[illegible]	2202	320		
									[illegible]	1910	[illegible]	[illegible]	[illegible]		
									1768	1816	[illegible]	2122	300		
									1792	1839	1671	2216	325		
									[illegible]	1854/40	1806/91	2191/90	313/11		
	Air	6.8(8)	2.4(13) (air irradiation)	1.2(14)	4.9(12)	16			[illegible]	2089	2065	2276	120	82	--
									1944	1928	1857	1928	[illegible]		
									1913	1913	--	1913	55		
									2105	2105	1913	2009	110		
									1913	1937	1889	2061	110		
									1980/76	1994/83	1931/101	2041/156	99/26		

TABLE C-1′. (Continued)

Material Trade Name	Test Condition	Radiation Exposure: Gamma [ergs/gm(C)]	Neutron (n/cm²): Thermal	Neutron (n/cm²): >2.9 Mev	Neutron (n/cm²): >8.1 Mev	Time Until Test, days	Sample Weight: Original, gm	Sample Weight: Change, (%)	Tensile Strength* (psi): at 75% Elongation	Tensile Strength* (psi): at 50% Elongation	Tensile Strength* (psi): at 100% Elongation	Tensile Strength* (psi): Ultimate	Ultimate Elongation, percent	Temperature Avg. (F)	Press. Avg. (torr)
	Air	9.1(7)	7.8(12)	1.7(13)	7.0(11)	8	5.4292	-0.0007	1886	1933	1933	2452	320	80	1.7(-7)
			(vacuum irradiation)				5.4134	+0.0014	1941	1966	1975	2524	315		
							5.4191	+0.0031	1908	1956	1956	2318	305		
							5.3982	+0.0022	1908	1932	1956	2294	310		
							5.4775	-0.0030	1886	1233	1933	2523	330		
									1906/24	1944/15	1951/18	2422/99	316/11		
	Air	3.9(8)	1.9(13)	4.4(13)	1.7(12)	7	5.3818	-.0007	1849	1867	1887	2231	335	90	4(-7)
			(vacuum irradiation)				5.3837	+.0004	1893	1922	1922	2246	315		
							5.4215	[illegible]	1917	1941	1941	2427	355		
							5.4641	[illegible]	1893	1893	1932	2294	336		
							5.4252	[illegible]	1870	1899	1889	1889	100		
									1886/29	1904/32	1914/23	2217/23	287/110		
Kel-F-81	Air	0	0	0	0	—			4622	4622	4558	5697	176	—	—
			(control specimens)						4495	4561	4462	5619	180		
									—	4266	4242	5081	200		
									4221	4221	4347	5513	180		
									4171	4234	4265	6070	185		
									4377/219	4385/26	4375/136	5636/425	184/10		
	Air	6.5(7)	3.5(12)	1.4(13)	6.0(11)	14			—	—	—	5377	15*	80	—
			(air irradiation)						4178	4211	4275	5409	205		
									4022	4106	4149	5080	150		
									4204	4016	4141	5239	205		
									4135/108	4111/115	4165/79	5276/160	187/32		
	Air	1.5(8)	3.3(12)	3.0(13)	1.1(12)	14			4166	4299	4166	5477	180	80	—
			(air irradiation)						4275	4312	4344	5431	200		
									4137	4269	4225	5325	185		
									4313	4357	4313	5237	190		
									4204	4204	4141	5334	180		
									4219/76	4248/111	4238/87	5351/103	187/9		
	Air	6.8(8)	2.4(13)	1.2(14)	4.9(12)	14			3876	—	—	5276	40*	82	—
			(air irradiation)						3888	3920	3964	5227	190		
									4016	3984	4016	5173	210		
									3941	4027	4071	5110	215		
									4142	3964	3953	5249	200		
									3973/114	3979/52	4006/57	5207/71	204/12		
	Air	7.5(7)	4.6(12)	5.2(12)	2.35(11)	8	22.2416	-0.0037	4458	4458	4392	5605	104	80	1.7(-7)
			(vacuum irradiation)				22.5782	-0.0034	4590	4526	4717	5610	150		
							22.1467	+0.0002	4375	4408	4637	4474	170		
							16.6356	-0.0019	4434	4304	4521	5521	145		
							23.5746	-0.0015	4514	4358	4483	5821	182		
									4474/92	4411/95	4550/140	5406/579	350/34		

TABLE C-14. (Concluded)

Material Trade Name	Test Condition	Radiation Exposure: Gamma [ergs/gm(C)]	Neutron (n/cm²): Thermal	Neutron (n/cm²): E>2.9 Mev	Neutron (n/cm²): E>3.1 Mev	Time Until Test, days	Sample Weight: Original, gm	Sample Weight: Change, gm	Tensile Strength* (psi): at 25% Elongation	Tensile Strength* (psi): at 50% Elongation	Tensile Strength* (psi): at 100% Elongation	Tensile Strength* (psi): Ultimate	Ultimate Elongation, percent	Temperature Avg., (F)	Press. Avg., (torr)
Kel-F-81	Air	9.1(7)	7.8(12)	1.7(13)	7.0(11)	8	22.2692	-0.0006	4405	4340	4405	5636	202	80	1.7(-7)
			(vacuum irradiation)				22.4512	-0.0007	3841	3777	3809	5633	168		
							21.9510	-0.0040	4487	4520	—	5626	55**		
							16.6468	-0.0010	4539	4628	4494	5384	157		
							23.5801	+0.0002	4328	4268	4328	5440	172		
									4320/300	4307/366	4259/333	5544/108	175/22		
	Air	4.45(8)	7.95(13)	5.45(13)	2.1(12)	10	22.6[illegible]9	-0.0008	4437	4405	4373	5733	165	90	1(-7)
			(vacuum irradiation)				22.0[illegible]	-0.0068	4599	4632	4567	5798	185		
							16.7075	+0.0007	4379	4207	4379	5367	175		
							16.7023	-0.0007	4396	4252	4296	5436	180		
							23.1123	-0.0001	4486	4330	4267	5616	200		
									4439/130	4365/183	4376/129	5590/135	181/15		

* Values given as: average value/standard deviation on an individual basis.

** Data point not used in average.

TABLE C-15. EFFECT OF NUCLEAR RADIATION ON FLUOROCARBONS(6,7)

Material Trade Name	Test Condition	Radiation Exposure: Gamma [ergs/gm(C)]	Radiation Exposure: Neutron (n/cm²) Thermal	Radiation Exposure: Neutron (n/cm²) >2.9 Mev	Radiation Exposure: Neutron (n/cm²) >8.1 Mev	Time Until Test, days	Sample Weights: Original, gm	Sample Weights: Change, gm	Tensile Strength* (psi): at 25% Elongation	Tensile Strength* (psi): at 50% Elongation	Tensile Strength* (psi): at 100% Elongation	Tensile Strength* (psi): Ultimate	Ultimate Elongation, percent	Temperature Avg., (F)	Press. Avg., (torr)
Duroid 5600 glass-fiber filled Teflon	Air	0	0 (control specimens)	0	0	—	—	—	—	—	—	2219 2492 2262 2167 2316 2291/140	0.82 0.91 0.79 0.69 0.94 0.83/.11	—	—
	Air	1.5(8)	3.3(12) (air irradiation)	3.0(13)	1.1(12)	10						2193 1596 1800 1972 1890 1890/257	0.48 0.47 0.41 0.64 0.43 0.51/.10	80	—
	Air	6.8(8)	2.4(13) (air irradiation)	1.2(14)	4.9(12)	10						1609 1666 1582 1359 1818 1599/197	0.42 0.38 0.34 0.27 0.47 0.38/.09	82	—
	Air	1.36(9)	1.8(13) (air irradiation)	2.5(14)	9.5(12)	10						1542 1646 1492 1560/91	0.34 0.37 0.45 0.39/.06	82	—
	Air	1.8(8)	8.4(12) (vacuum irradiation)	1.85(13)	7.6(11)	8	23.3102 23.8341 23.0300 23.8446 23.8812	+0.0153 +0.0127 +0.0137 +0.0105 +0.0090				2001 2206 1976 2066 2115 2073/100	0.56 0.74 0.57 0.63 0.60 0.62/.07	80	1.(-7)
	Air	4.2(8)	1.9(13) (vacuum irradiation)	4.5(13)	1.8(12)	8	22.9615 22.8704 23.8973 22.9133 23.7812	-0.0033 -0.0036 -0.0088 -0.0038 -0.0038				2243 2220 1930 2323 2375 2218/191	0.65 0.75 0.86 0.77 0.74 0.75/.09	90	4.(-7)
	Air	8.8(8)	2.8(13) (vacuum irradiation)	1.7(14)	6.4(12)	8	23.0349 22.9674 23.5230 23.7765 22.8814	-0.0060 -0.0048 -0.0077 -0.0056 -0.0043				2148 2358 2151 2351 2234 2250/95	0.66 0.50 0.72 0.73 0.91 0.70/.18	90	4(-7)

TABLE C-15. Continued)

Material Trade Name	Test Condition	Gamma [ergs/gm(C)]	Radiation Exposure Neutron (n/cm²) Thermal	E>2.9 Mev	E>8.1 Mev	Time Until Test, days	Sample Weights Original, gm	Change, gm	Tensile Strength[a] (psi) at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Ultimate Elongation, percent	Temperature Av (F)	Press. Avg. (torr)
Kynar	Air	0	0 (control specimens)	0	0	—						4000 5133 4883 6167 5500 7000 5[illegible] 559 .1109	— — — 10 5 10 10 8..5/2.42	—	—
	Air	0	0 (vendor data)	0	0	—						7000	300		
	Air	6.5(7)	3.5(12) (air irradiation)	1.4(13)	6.0(11)	13						5167 6000 6167 7467 5033 5967/975	10 10 5 10 25 12/7.6	80	—
	Air	1.5(8)	3.3(12) (air irradiation,	3.0(13)	1.1(12)	13						5850 6117 5833 6367 5950 6023/226	10 10 10 5 10 9/2.24	80	--
	Air	1.36(9)	1.8(12) (air irradiation)	2.5(14)	9.5(12)	13						6367 6200 6233 7333 5833 6793/982	10 10 5 5 10 8/2.74	82	—
	Air	6.2(7)	4.5(12) (vacuum irradiation)	6.3(12)	2.8(12)	9	1.[illegible]03 1.58[illegible] 1.6308 1.4761 1.5520	0.0000 -0.0009 -0.0015 +0.0009 +0.0006				6550 5383 5417 5417 5167 5587/545	5 20 15 10 15 13.25/6.77	80	1.7(-7)
	Air	1.8(8)	8.4(12) (vacuum irradiation)	1.85(13)	1.6(11)	8	1.5288 1.5462 1.5446 1.6016 1.5072	+0.0019 +0.0091 +0.0024 +0.002[illegible] +0.00[illegible]				5283 4583 5667 6000 5283 5363/529	15 5 5 — 10 8.75/4.80	80	1.7(-7)
	Air	9.4(8)	2.8(13) (vacuum irradiation)	1.5(14)	5.6(12)	10						5667 5333 5250 6117 5800 5633/359	10 — 10 10 — 10/0	90	4(-7)

TABLE C-15 (Concluded)

Material Name	Test Condition	Radiation Exposure: Gamma ergs/gm(C)	Radiation Exposure: Neutron (n/cm²) Thermal	Neutron (n/cm²) E>2.9 Mev	Neutron (n/cm²) E>8.1 Mev	Time Until Test, days	Sample Weights: Original, gm	Sample Weights: Change, gm	Tensile Strength* (psi) at 5% Elongation	Tensile Strength* (psi) at 50% Elongation	Tensile Strength* (psi) at 100% Elongation	Tensile Strength* (psi) Ultimate	Ultimate Elongation, percent	Temperature Avg., (F)	Press. Avg., (torr)
Tedlar (2 mil)	Air	0	0 (control specimen)	0	0	—			5900 5750 5750 [illegible] [illegible] 5830/107	6150 5750 5750 6000 5900 5910/172	— — — — — —	9900 9250 9650 9350 9150 9460/322	245 227 278 255 230 247/23	—	—
	Air	1.5(8)	3.3(12) (air irradiation)	3.0(13)	1.1(12)	12			5250 5500 5500 5630 5475/172	5400 5350 5400 5650 5450/129	5750 5500 5400 5650 5575/150	8350 8350 8400 8650 8680/451	255 [illegible] [illegible] 250 261/13	80	—
	Air	1.55(9)	1.8(13) (air irradiation)	2.5(14)	9.5(14)	12			5350 5650 5750 5250 5400 5470/215	5350 5750 5750 5350 5400 5520/172	5400 5750 5850 5500 5500 5600/193	7250 7750 8700 8400 8000 8020/623	190 225 260 230 260 233/30	82	—
	Air	9.1(7)	7.8(12) (vacuum irradiation)	1.7(13)	7.0(11)	9	0.3186 0.3178 0.3175 0.3182 0.3168	+0.0004 0.0000 -0.0099 +0.0002 +0.0004	6000 6250 6100 6250 5900 6100/150	6250 — 5750 — 6000 6000/295	6500 — — — 6150 6325/x	10000 7500 10400 9650 10250 9560/1247	260 — 285 220 320 271/49	[illegible]0	1.7(-7)
	Air	4.45(8)	1.95(13) (vacuum irradiation)	5.45(13)	2.1(12)	8	0.3218 0.3162 0.3250 0.3179 0.3132	-0.0008 +0.0003 +0.0001 +0.0003 +0.0002	— 5800 6100 [illegible] 6350 6100/267	— 5800 6150 [illegible] 6000 6025/170	— — — — 6250 —	— 9100 9650 9300 [illegible] 9425/267	225 218 240 240 [illegible] 235/14	90	4(-7)
	Air	[illegible].4(8)	2.8(13) (vacuum irradiation)	.5(14)	5.6(12)	8	[illegible] 0.3135 0.3249 0.3225 0.3242	[illegible] -0.0009 +0.0003 +0.0003 -0.0002	— [illegible] 6150 6000 6250 6075/170	5750 [illegible] [illegible] 6100 6400 6060/207	5900 — [illegible] [illegible] — 6100/207	9300 6950 8350 [illegible] 9600 8990/408	235 220 225 220 [illegible] 228/5	90	4(-7)

* Values given as: average value/standard deviation on an individual basis.

TABLE C-16. VACUUM DATA FROM OTHER WORK[63]

Mol % Gases Evolved

	Weight of Samples, gm	Temperature, C	H_2O	CO_2	N_2	O_2	Volume of Gas, cc/gm
Teflon TFE#	0.9010	71	12.07	--	62.51	25.42	0.0067
	0.9010	180	14.10	--	64.64	21.26	0.0164
	0.9010	200	6.28	1.78	72.88	19.06	0.0172

\# Pressure at 10^{-6} mm Hg.

TABLE C-17. PHYSICAL PROPERTIES OF TEFLON FILMS IRRADIATED WITH MONOCHROMATIC LIGHT[58]

Incident Energy, joules/cm²	Wavelength, mμ	Tensile Strength, 10^3 psi	Young's Modulus, 10^5 psi	Elongation, per cent
53.3	244	10.4	--	142
78.5	244	11.36	4.4	178
103.0	244	9.08	4.6	120
252.0	244	6.52	5.6	44
<u>Irradiated with Nitrogen</u>				
0	-	4.02	0.0965	1164
5644	369	4.14	0.167	850
649	314	4.40	0.144	950
1180	314	3.68	0.174	745
132	244	3.68	0.0832	725
300	244	3.48	0.076	700
497	244	3.08	-	800

Each of the observations recorded was an average of two separate measurements, except for the controls, which were averages of 8-10.

TABLE C-18. PHYSICAL PROPERTIES OF TEFLON FILMS IRRADIATED WITH A G30T8 LAMP(58)

Irradiation Time, hours	Tensile Strength, 10^3 psi	Young's Modulus, 10^5 psi	Elongation, per cent
C. Teflon Irradi . Nitrogen			
0	4.02	0.0965	1164
92	4.00	-	1086
120	3.90	0.0972	750
559	3.79	0.0968	770
D. Teflon Irradiated in a Vacuum			
40	3.80	0.0564	1160
68	3.46	-	-
139	3.04	0.0590	520
146	2.85	0.057	500
167	2.59	0.0510	520

TABLE C-19. TEST RESULTS – BEFORE AND AFTER THERMAL IRRADIATION(68)

Nylon 66

Sample Designation	Pretreatment	Temperature, C	Time of Exposure, hours	Atmosphere	Physical Condition	Solvent	Concentration, g/dl	Viscosity at 30 C, cp	Relative* Viscosity	Inherent** Viscosity	Melting Point, C
0	—	-	—	—	Transparent flexible	CaCl in CH_3OH	2.00	73.51	2.38	0.43355	254-260
1	—	66	3	Vacuum	No change	Ditto	2.00	121.71	3.94	0.68559	251-255
2	—	66	7	Vacuum	Ditto	"	2.00	121.41	3.94	0.68559	254-258
3	—	66	24	Vacuum	"	"	2.00	105.71	3.42	0.61482	255-258
4	2 hr vac at 100	275	2	Vacuum	Fused, dark	"	Insol.	—	—	—	213-260
5	2 hr vac at 150	275	2	Vacuum	Fused, dark	"	Insol.	—	—	—	213-258
6	4 hr vac at 100	200	2	Vacuum	Yellow, slightly brittle	"	2.00	83.66	2.71	0.49848	251-254
7	4 hr vac at 66	250	2	Vacuum	Slight yellowing	"	2.00	106.91	3.46	0.62063	256-258
8	24 hr vac at 89	180	4	Vacuum	Slight yellowing	"	2.00	87.98	2.85	0.52366	254-256
9	24 hr vac at 66	180	4	Vacuum	Slight yellowing	"	2.00	93.36	3.02	0.55[illegible]	254-256

* Relative viscosity = N_r = viscosity of the solution/viscosity of the solvent.
Viscosity of the solvent $CaCl_2$-CH_3OH = 30.85 cp.

** Inherent viscosity = $N_i = l_n N_r / c$.

TABLE C-20. PHYSICAL PROPERTIES OF PLASTIC FILMS IRRADIATED WITH MONOCHROMATIC LIGHT(58)

Incident Energy, joules/cm^2	Wavelength, mμ	Tensile Strength, 10^3 psi	Young's Modulus, 10^5 psi	Elongation, percent
A. Polyethylene Irradiated in Nitrogen				
0	-	5.52	5.90	512
179	369	7.04	2.49	270
2200	369	7.49	4.6	342
3160	369	5.77	4.62	343
475	314	5.59	4.95	290
623	314	6.28	2.25	290
1053	314	4.09	4.92	225
87	244	5.86	5.39	95
290	244	4.05	6.17	50
400	244	2.07	4.93	16
A. Polyethylene Irradiated in a Vacuum				
547	244	7.41	4.09	232
595	244	7.48	5.51	190
B. Mylar Irradiated in Nitrogen				
0	-	17.3	2.64	46
1269	369	20.1	1.32	36
3096	369	7.68	1.36	40
585	314	14.46	1.5	17
921	314	6.30	7.75	18
58	244	16.7	2.47	47
57	244	15.6	2.16	28
225	244	12.46	2.69	7
314	244	12.1	3.02	11
B. Mylar Irradiated in a Vacuum				
1375	244	6.56	1.42	11

TABLE C-20. (Concluded)

Incident Energy, joules/cm²	Wavelength, mμ	Tensile Strength, 10^3 psi	Young's Modulus, 10^5 psi	Elongation, percent
C. Nylon Irradiated in Nitrogen				
0	-	11.32	4.6	153
158.5	369	11.24	4.0	203
376.1	369	10.28	6.8	157
1234	369	11.6	-	133
2700	369	11.02	6.4	137
89	314	10.8	6.4	140
336	314	11.04	5.4	168
1234.4	314	11.56	6.5	133
1450	314	10.82	5.2	182

TABLE C-21. PHYSICAL PROPERTIES OF PLASTIC FILMS IRRADIATED WITH A G30T8 LAMP(58)

Irradiation Time, hour	Tensile Strength, 10^3 psi	Young's Modulus, 10^5 psi	Elongation, percent
A. Polyethylene Irradiated in Nitrogen			
0	5.52	5.90	512
8	6.24	4.4[illegible]	550
24	4.32	2.[illegible]	200
47	2.82	5.62	95
72	2.08	4.95	6
154	1.57	3.9	7
B. Polyethylene Irradiated in Vacuum			
22	6.24	5.70	520
48	4.82	5.73	270
68	5.02	7.13	1[illegible]
168	3.28	3.21	[illegible]
C. Teflon Irradiated in Nitrogen			
[illegible]	4.02	0.0965	1164
92	4.00	--	1086
120	3.90	0.0972	750
559	3.79	0.0968	770
D. Teflon Irradiated in a Vacuum			
40	3.80	0.0564	1160
68	3.46	--	--
139	3.04	0.0590	520
146	2.85	0.057	500
167	2.59	0.051[illegible]	520
E. Nylon Irradiated in Nitrogen			
0	8.32	2.46	131
42	8.96	3.31	135
78	6.32	3.08	80
180	3.56	6.17	14

TABLE C-21. (Concluded)

Irradiation Time, hour	Tensile Strength, 10^3 psi	Young's Modulus, 10^5 psi	Elongation, percent
F. Nylon Irradiated in a Vacuum			
8	8.36	2.2	230
24	7.92	3.75	260
68	7.06	3.75	182
140	7.04	5.73	161
190	6.8	11.03	111
G. Mylar Irradiated in Nitrogen			
0	17.3	2.64	46
22	13.5	1.28	21
45	13.6	--	14
161	10.5	1.98	12
192	9.7	1.37	12
H. Mylar Irradiated in a Vacuum			
28	18.0	1.89	54
68	17.5	1.63	58
120	15.6	1.30	30
172	14.0	2.14	11
190	13.8	1.90	14

TABLE C-22. EFFECTS OF RADIATION ON MYLAR(7)

Material Trade Name	Test Condition	Radiation Exposure: Gamma Ergs/gm(C)	Neutron (n/cm²): Thermal	Neutron (n/cm²): E>2.9 Mev	Neutron (n/cm²): E>8.1 Mev	Time Until Test, days	Sample Weights: Original, gm	Sample Weights: Change, gm	Tensile Strength* (psi): at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Ultimate Elongation, percent	Temperature Avg., (F)	Press. Avg., (torr)
Mylar C	Air	0	0 (control specimens)	0	0	—	—	—	16,300	19,200	—	21,300	60		--
									16,000	[illegible]	—	—	—		
									16,200	16,700	24,500	24,500	[illegible]		
									16,200	17,500	24,000	28,500	21		
									16,300	18,500	24,500	26,[illegible]	[illegible]		
									16,200/129	18,520/731	24,333/295	25,700/[illegible]	[illegible]		
	Air	0.6(8)	2.4(13) (air irradiation)	1.2(14)	4.9(1[illegible])	13	—	—	15,500	17,500	21,000	23,[illegible]00		[illegible]	--
									15,200	17,500	1[illegible],300	24,000	---		
									14,300	16,500	—	16,500	[illegible]0		
									15,500	17,500	22,500	25,100	120		
									15,000	17,000	20,500	22,500	105		
									15,200/301	17,200/430	20,[illegible]5/155[illegible]	22,[illegible]00/421[illegible]	97/26		
	Air	1.36(9)	1.6(13) (air irradiation)	2.5(1[illegible])	9.5(12)	13	—	—	15,500	16,300	21,500	23,[illegible]00	105	82	—
									15,200	17,500	21,500	24,[illegible]00	125		
									15,700	18,000	22,500	24,400	105		
									15,000	17,000	—	19,300	70		
									15,2[illegible]0	17,000	21,000	22,500	105		
									15,320/301	17,560/559	21,625/729	22,040/[illegible]	102/24		
	Air	0.0(9)	— (air irradiation)	1.20(15)	—	16	—	—	16,000	—	—	16,700	35	100	--
									—	—	—	18,100	60		
									—	—	—	20,000	70		
									—	—	—	—	—		
									—	—	—	19,500/1949	55/21		
Mylar C	Air	4.45(6)	1.95(1[illegible]) (vacuum irradiation)	5.45(13)	2.1(12)	9	0.1470	-0.0014	16,300	18,600	—	24,000	90	90	4 -7)
							0.1496	-0.0027	—	—	—	—	110		
							0.1503	-0.0007	16,500	19,000	—	21,300	[illegible]0		
							0.1462	-0.0012	16,500	18,500	22,000	27,300	120		
							0.1494	-0.0002	16,500	20,000	26,000	28,[illegible]00	108		
									16,450/97	19,250/729	24,000/x	25,325/22[illegible]3	100/21		
	Air	9.1(8)	2.8(13) (vacuum irradiation)	1.6(14)	6.0(13)	9	0.1475	-0.0016	16,300	18,500	24,500	24,300	100	90	4 -7)
							0.1465	+0.0011	16,000	19,000	—	23,700	90		
							—	—	—	—	—	—	—		
							0.1422	0.0000	16,100	19,000	—	20,100	96		
							0.1433	-0.0006	[illegible],200	19,200	—	26,000	98		
									[illegible]	18,675/24[illegible]	—	23,725/2574	96/5		
Mylar A	Air	5.9(9)	1.8(14) (vacuum irradiation)	6.56(14)	—	7	1.4112	-0.0010	15,300	16,700	—	17,800	110	160	8 -7)
							1.3924	0.0000	[illegible]	16,[illegible]	—	17,500	95		
							1.3972	-0.000[illegible]	[illegible]	16,600	—	[illegible]	1[illegible]		
							1.3993	-0.000[illegible]	[illegible]	16,700	—	[illegible]	[illegible]5		
							1.4003	+0.0001	[illegible]	16,500	17,300	17,[illegible]	100		
									16,060/516	16,700/129	—	17,640/430	97/15		
	Air	1.05(10)	1.32(14) (vacuum irradiation)	1.65(15)	5.9(13)	7	1.4154	-0.0010	—	—	—	19,200	—	160	8'-7)
							1.4196	-0.0021	—	—	—	16,780	80		
							1.4013	-0.0014	—	—	—	17,500	20		
							1.3976	+0.0001	15,800	15,800	—	15,300	50		
							1.3982	-0.0021	—	—	—	16,000	15		
									—	—	—	17,056/1442	41/32		
							1.3976	+0.0001	15,000	15,000	—	15,[illegible]	50		
							1.39[illegible]	-0.0021	—	—	—	16,000	15		
									—	—	—	17,056/1442	41/32		

TABLE C-22. (Concluded)

Material Trade Name	Test Condition	Gamma ergs/gm(C)	Radiation Exposure: Neutron (n/cm²) Thermal	E>2.9 Mev	E>8.1 Mev	Time Until Test, days	[illegible]ple Weights: Original, gm	Change, gm	Tensile Strength* (psi): at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Ultimate Elongation, percent	Temperature Avg. (F)	Press. Avg. (torr)
Mylar A	Air	0	0	0	0	—	—	—	16,300	17,000	19,000	20,500	119	—	---
			(control specimens)						16,600	17,600	19,700	22,000	132		
									16,900	17,600	19,800	19,800	100		
									16,600	17,500	19,500	—	—		
									17,000	17,500	19,400	20,200	119		
									16,680/301	17,480/344	19,480/344	20,625/946	115/14		
	Air	6.8(8)	2.4(13)	1.2(14)	4.9(12)	16	—	—	16,500	17,200	18,600	21,800	140	82	—
			(air irradiation)						16,500	17,200	18,600	22,000	130		
									16,800	17,500	19,200	21,[illegible]	125		
									16,600	17,500	18,800	21,[illegible]	150		
									16,350/389	17,350/146	18,850/291	21,625/[illegible]	136/12		
	Air	1.07(10)	1.9(14)	2.3(15)	8.2(13)	16	—	—	15,400	15,700	—	16,000	80	100	—
			(air irradiation)						15,600	15,800	—	16,300	—		
									15,500	15,900	—	16,500	75		
									15,500	15,900	16,200	16,200	100		
									15,500	16,800	—	16,600	60		
									15,500/[illegible]	16,020/473	—	16,360/344	79/19		
	Air	4.45(8)	1.95(13)	5.45(13)	2.1(12)	9	1.4195	+0.0003	16,500	17,500	19,200	21,500	131	90	4(-7)
			(vacuum irradiation)				1.4059	+0.0001	16,500	17,300	19,000	19,500	105		
							1.4067	+0.0005	16,500	17,200	19,200	21,500	132		
							1.4190	0.0000	16,500	17,300	19,500	22,000	135		
							1.4[illegible]84	+0.0019	16,500	17,300	19,300	19,700	110		
									16,500/0	17,320/125	19,240/215	20,840/1075	123/13		

* Values given as: average value/standard deviation on an individual basis.

TABLE C-23. HIGH-VACUUM TESTING OF MYLAR PLASTIC FILM(57)

Test No.	No. of Samples	Mylar Thickness, mils	Aluminum Coating Thickness, A	Aluminum Coating Application	Test Duration, hours	Temperature, C	Ultimate Vacuum, mm Hg	Weight Loss, μ g/sq cm	Remarks
1	1 1 1	3 1 0.1	None	None	72	Room	10^{-6}	8.6 14 0.0	Apparent decrease in flexibility
2	1 1 1	1	250	Coated on one side only	72	Room	10^{-6}	0.0 0.0 0.0	Apparent decrease in flexibility
3	Same samples as above		250 100 50	Coated on one side only	72	100	10^{-5}	20 13 17	Warping, wrinkling, and loss of flexibility
4	2 2 2	3	None Coated Coated	Uncoated One side* Both sides*	72	150	10^{-5}	Results invalid, due to error in weighing	Warping, wrinkling, and loss of flexibility
5	2 2 2	3	None Coated Coated	Uncoated One side* Both sides*	72	150	10^{-5}	100.0, 113.0 19, [illegible]4 31, 31	Warping, wrinkling, and loss of flexibility

* Thickness not regulated on these samples.

TABLE C-24. EFFECTS OF VACUUM AND OF VACUUM WITH ULTRAVIOLET RADIATION ON FILMS(46)

Material	Type of Exposure*	Temperature, F	Exposure Time, hours	Weight Change, per cent	Tensile Strength: Before Exposure, psi	Tensile Strength: After Exposure, psi	Tensile Strength: Change, per cent	Break Elongation: Before Exposure, in./in.	Break Elongation: After Exposure, in./in.
Polyethylene terephthalate, aluminized one side	Vacuum	75 to 80	168	-0.02	25,200	23,600	-6.4	1.08	0.96
	Vacuum	55 to 60	770	+0.04	26,200	23,000	-12.2	1.414	1.039
	Vacuum and ultraviolet	85 to 95	770	+0.37	26,200	14,900	-43.0	1.414	0.174
Polyvinyl fluoride, Type 20, clear	Vacuum	75 to 80	168	Not measurable	12,150	12,375	+1.9	1.112	1.135
	Vacuum	55 to 60	770	+0.29	14,700	13,400	-8.8	0.965	0.915
	Vacuum and ultraviolet	85 to 95	770	-1.57	14,700	10,500	-28.7	0.965	0.296

* Maximum vacuum pressures on the order of 5×10^{-6} mm Hg.

TABLE C-25. EFFECTS OF VACUUM AND OF VACUUM WITH ULTRAVIOLET RADIATION ON SEAMED FILMS*(46)

Exposure Time of 770 Hours

Material	Time of Exposure**	Temperature, F	Weight Change, per cent	Tensile Strength: Before Exposure, psi	Tensile Strength: After Exposure, psi	Tensile Strength: Change, per cent
Polyethylene terephthalate, 1 mil, aluminized one side, butt seamed with 1/2 in. heat-sealable polyester-resin-coated polyethylene-terephthalate tape	Vacuum	55 to 60	0.00	22,200	22,100	-0.2
	Vacuum and ultraviolet	85 to 95	+0.24	22,200	15,600***	-29.5
Polyethylene terephthalate, 1 mil, aluminized one side, butt seamed with 3/4-in. pressure-sensitive, silicone-adhesive-coated polyethylene-terephthalate tape	Vacuum	55 to 60	+0.06	15,000	15,100	+0.7
	Vacuum and ultraviolet	85 to 95	+0.08	15,000	15,800***	+5.3
Polyethylene terephthalate, 1 mil, aluminized one side, butt-seamed with 1/2-inch polyethylene-terephthalate tape and solvent-type adhesive	Vacuum	55 to 60	-0.57	15,600	16,900	+8.1
	Vacuum and ultraviolet	85 to 95	-1.13	15,600	8,100	-48.3
Polyethylene terephthalate, 1 mil, aluminized one side, butt seamed with 1/2-inch polyethylene-terephthalate tape and Pliobond+ solvent-type adhesive	Vacuum	55 to 60	-0.71	19,500	21,300	+9.4
	Vacuum and ultraviolet	85 to 95	-3.23	19,500	14,700***	-24.5
Polyvinyl fluoride, 1 mil, clear, 1/16-inch lap-seamed, heat-sealed	Vacuum	55 to 60	+0.04	9,400	9,600	+2.1
	Vacuum and ultraviolet	85 to 95	-1.48	9,400	9,800	+5.0

* All values are the averages of three specimens. Tapes applied to nonaluminized side.

** Maximum vacuum pressures on the order of 5×10^{-6} mm Hg.

*** Specimen failure did not occur in seam.

\+ Goodyear Tire and Rubber Company adhesive.

TABLE C-26. TEST ENVIRONMENTS AND RESULTS OF STATIC TESTS: HIGH DENSITY POLYETHYLENE(7)

Material Trade Name	Test Condition	Radiation Exposure: Gamma (ergs/gm(C))	Neutron (n/cm²): Thermal	Neutron (n/cm²): E>2.9 Mev	Neutron (n/cm²): E>8.1 Mev	Time Until Test, days	Sample Weight: Original, gm	Sample Weight: Change, gm	Tensile Strength(a) (psi): at 25% Elongation	at 50% Elongation	at 100% Elongation	Ultimate	Ultimate Elongation, per cent	Temperature, average, (F)	Pressure, average, (torr)
Marlex 6002 (14 mil)	Air	0	0	0	0	—			3000	2714	2714	4071	785	--	--
			(control specimens)						3286	2571	2357	2571	1100		
									3043	3014	2571	3343	775		
									3507	2943	2507	3661	960		
									3700	3107	2643	4086	960		
									3414	2921	2864	3229	660		
									[illegible]	3014	2943	3521	910		
									3406/264	2898/198	2657/217	3497/560	907/120		
	Air	1.5(8)	3.3(12)	3.0(13)	1.1(12)	14			—	—	—	4286	—	80	--
			(air irradiation)						—	—	—	4071	—		
									—	—	—	3893	—		
									3571	3071	2571	[illegible]	~600		
									3571	3071	2571	4054/191	~500		
	Air	1.36(9)	1.8(13)	2.5(14)	9.5(12)	14			—	—	—	4307	20	52	—
			(air irradiation)						—	—	—	4079	15		
									—	—	—	4057	20		
									—	—	—	3993	5		
									—	—	—	4000	10		
									--	—	—	4087/135	14/6		
	Air	1.8(8)	8.4(12)	1.85(13)	7.6(11)	8	1.3798	+0.0002	4214	3464	—	4357	720	80	[illegible]
			(vacuum irradiation)				1.3510	+0.0007	2929	—	—	4286	975		
							1.2338	+0.0001	3329	—	—	4107	1030		
							1.2232	+0.0004	3657	2714	—	3904	690		
							1.[illegible]505	-0.0002	4107	—	—	4250	825		
									3807/552	3098/—	—	4193/169	845/140		
	Air	4.5(8)	1.[illegible](13)	5.45(13)	2.1(12)	10	1.3427	+0.[illegible]	3571	3000	—	4429	800	90	[illegible]
			(vacuum irradiation)				1.3553	-0.0005	4071	—	—	4500	—		
							1.[illegible]485	-0.0003	3786	3071	—	4464	430		
							1.[illegible]441	-0.0004	4143	3286	—	4393	831		
							1.3169	-0.0003	3786	2857	—	4212	775		
									3871/246	3054/164	—	4400/123	711/198		
	Air	9.4(8)	2.8(13)	1.6(14)	6.0(12)	10	1.2526	+0.0012	3714	3071	—	3679	725	90	[illegible]
			(vacuum irradiation)				1.2871	+0.0012	—	—	—	—	—		
							1.2490	+0.0007	4071	3143	2643	4214	640		
							1.3067	+0.0[illegible]	-	—	—	—	—		
							1.3116	+0.0[illegible]		2857	—	4429	660		
									[illegible]/25	3024/169	2643	4107/443	675/50		

(a) Values given as: average/standard deviation on an individual basis.

TABLE C-27. STRENGTH PROPERTIES OF NOMEX YARNS EXPOSED TO ELEVATED TEMPERATURE(76)

	Tenacity, grams/denier			Strength Retained, %		
	Natural	Int. Orange	Olive Green	Natural	Int. Orange	Olive Green
Original	5.92	5.85	5.58			
Original + 2 Hr at 400 F	5.54	6.03	5.83	93.6	103.07	104.4
Original + 2 Hr at 500 F	5.09	5.50	4.20	85.9	94.0	75.5
Original + 2 Hr at 600 F	2.13	3.29	2.86	37.0	56.3	51.3

TABLE C-28. ELONGATION PROPERTIES OF NOMEX YARNS EXPOSED TO ELEVATED TEMPERATURE(76)

	Elongation, %			Elongation Retained, %		
	Natural	Int. Orange	Olive Green	Natural	Int. Orange	Olive Green
Original	14.2	11.2	12.0			
Original + 2 Hr at 400 F	12.3	12.6	12.0	86.6	112.5	100.0
Original + 2 Hr at 500 F	10.3	11.6	7.6	72.5	103.5	63.3
Original + 2 Hr at 600 F	2.2	5.5	3.9	15.5	49.2	32.5

TABLE C-29. STRENGTH PROPERTIES OF NOMEX YARNS EXPOSED TO GAMMA RADIATION AND/OR ELEVATED TEMPERATURE (400 F)[76]

	Tenacity, grams/denier			Strength Retained, %		
	Natural	Int. Orange	Olive Green	Natural	Int. Orange	Olive Green
Original	5.92	5.85	5.58			
Original + 2 Hr at 400 F	5.54	6.03	5.83	93.6	103.07	104.4
Gamma, 7.0×10^{8} (a)	5.32	5.95	5.69	89.8	101.7	101.9
Gamma, 7.0×10^{8} + 2 Hr at 400 F	6.22	6.46	5.70	105.06	110.4	102.1
Gamma, 7.0×10^{8}/400 F(b)	5.30	5.54	5.81	88.5	94.7	104.1
Gamma, 7.0×10^{8}/400 F + 2 Hr at 400 F(b)	5.40	5.82	5.51	91.4	99.5	98.8
Gamma, 7.0×10^{8}/400 F + 2 Hr at 500 F	4.41	5.26	2.38	74.5	89.9	42.7
Gamma, 7.0×10^{8}/400 F + 2 Hr at 600 F	2.56	2.87	2.38(a)	43.3	49.1	42.7
Gamma, 1.4×10^{9} (a)	5.71	5.75	5.62	96.5	98.3	100.7
Gamma, 1.4×10^{9} + 2 Hr at 400 F	5.58	5.98	5.58	94.3	102.2	100.0
Gamma, 1.4×10^{9}/400 F	4.76	5.54	3.31	80.5	94.7	59.3
Gamma, 1.4×10^{9}/400 F + 2 Hr at 400 F	4.02	5.04	2.98	67.9	86.2	53.4
Gamma, 1.4×10^{9}/400 F + 2 Hr at 500 F	5.11	4.25	2.38	86.4	[illegible]	42.7
Gamma, 1.4×10^{9}/400 F + 2 Hr at 600 F	3.47	3.73	2.92(c)	58.6	63.8	52.5

(a) Normal operating temperature, approx. 100 F.
(b) F indicates gamma and temperature simultaneously + hours at F indicates oven aging.
(c) Frayed and brittle.
Note: Gamma exposure in ergs g^{-1}(C).

TABLE C-30. STRENGTH PROPERTIES OF NOMEX YARNS EXPOSED TO GAMMA RADIATION AND/OR ELEVATED TEMPERATURE (500 F)[76]

	Tenacity, grams/denier			Strength Retained, %		
	Natural	Int. Orange	Olive Green	Natural	Int. Orange	Olive Green
Original	5.92	5.85	5.58			
Original + 2 Hr at 500 F	5.09	5.50	4.23	85.9	94.0	75.5
Gamma, 7.0×10^{8}	5.32	5.95	5.69	89.9	101.7	101.9
Gamma, 7.0×10^{8} + 2 Hr at 500 F	4.60	4.74	2.0	77.7	81.9	35.9
Gamma, 7.0×10^{8}/500 F	4.68	5.0	3.14	79.1	85.5	56.3
Gamma, 7.0×10^{8}/500 F + 2 Hr at 400 F	4.52	4.9	2.76	76.4	83.8	49.5
Gamma, 7.0×10^{8}/500 F + 2 Hr at 500 F	4.34	4.8	3.36(b)	73.4	82.1	60.3
Gamma, 7.0×10^{8}/500 F + 2 Hr at 600 F	3.43	3.69	3.13(b)	57.9	63.1	56.1
Gamma, 1.4×10^{9}	5.71	5.75	5.62	96.5	98.3	100.7
Gamma, 1.4×10^{9} + 2 Hr at 500 F	4.43	4.33	2.69	74.8	82.6	48.2
Gamma, 1.4×10^{9}/500 F	3.67	4.89	4.52	62.0	83.6	81.1
Gamma, 1.4×10^{9}/500 F + 2 Hr at 400 F	4.24	4.72	4.06	71.6	80.7	72.8
Gamma, 1.4×10^{9}/500 F + 2 Hr at 500 F	4.19	4.46	4.20(b)	70.8	76.1	75.3
Gamma, 1.4×10^{9}/500 F + 2 Hr at 600 F	3.58	3.93(a)	3.55(a)	60.5	67.9	63.7

(a) Frayed and brittle.
(b) Frayed.
Note: Gamma exposure in ergs g^{-1}(C).

TABLE C-31. STRENGTH PROPERTIES OF NOMEX YARNS EXPOSED TO GAMMA RADIATION/AND/OR ELEVATED TEMPERATURE (600 F)[76]

	Tenacity, Grams/denier			Strength Retained, %		
	Natural	Int. Orange	Olive Green	Natural	Int. Orange	Olive Green
Original	5.92	5.85	5.58			
Original + 2 Hr at 600 F	2.18	3.29	2.86	37.0	56.3	51.3
Gamma, 7.0 x 10^8	5.32	5.95	5.69	89.9	101.7	101.9
Gamma, 7.0 x 10^8 + 2 Hr at 600 F	2.93	3.06	2.40	49.5	52.3	43.1
Gamma, 7.0 x 10^8/600 F	2.77	3.54	2.31	46.8	60.6	41.6
Gamma, 7.0 x 10^8/600 F + 2 Hr at 400 F	2.97	3.71	3.10	50.2	63.5	55.6
Gamma, 7.0 x 10^8/600 F + 2 Hr at 500 F	2.75	3.12	2.50[b]	46.8	53.4	44.8
Gamma, 7.0 x 10^8/600 F + 2 Hr at 600 F	2.09	3.04	2.65[a]	35.7	51.9	47.6
Gamma, 1.4 x 10^9	5.71	5.75	5.62	96.5	98.3	100.7
Gamma, 1.4 x 10^9 + 2 Hr at 600 F	2.74	2.74	2.54	46.2	46.8	45.5
Gamma, 1.4 x 10^9/600 F	2.13	1.05[a]	[illegible][a]	36.0	17.9	18.7
Gamma, 1.4 x 10^9/600 F + 2 Hr at 400 F	2.07	2.22	1.77[b]	34.8	37.5	31.8
Gamma, 1.4 x 10^9/600 F + 2 Hr at 500 F	2.30	2.35	2.12[a]	[illegible]	40.2	38.0
Gamma, 1.4 x 10^9/600 F + 2 Hr at 600 F	1.89[a]	2.41[a]	2.15[a]	31.9	[illegible]	38.6

(a) Frayed and brittle.

(b) Frayed.

Note: Gamma exposure in ergs g^{-1}(C).

TABLE C-32. ELONGATION PROPERTIES OF NOMEX YARNS EXPOSED TO GAMMA RADIATION AND/OR ELEVATED TEMPERATURE (400 F)[76]

	Elongation, %			Elongation Retained, %		
	Natural	Int. Orange	Olive Green	Natural	Int. Orange	Olive Green
Original	14.2	11.2	12.0			
Original + 2 Hr at 400 F	12.3	12.6	12.0	86.6	112.5	100.0
Gamma, 7.0 x 10^8	11.5	14.1	13.2	81.0	125.9	110.0
Gamma, 7.0 x 10^8 + 2 Hr at 400 F	16.2	14.9	11.5	114.1	133.0	95.8
Gamma, 7.0 x 10^8/400 F	11.2	12.1	12.9	78.9	108.1	107.5
Gamma, 7.0 x 10^8/400 F + 2 Hr at 400 F	11.8	12.2	11.6	83.1	108.9	96.5
Gamma, 7.0 x 10^8/400 F + 2 Hr at 500 F	7.8	10.5	2.5	54.9	93.7	20.9
Gamma, 7.0 x 10^8/400 F + 2 Hr at 600 F	3.3	4.2	2.8	23.3	37.5	23.3
Gamma, 1.4 x 10^9	15.0	12.9	13.7	105.6	115.2	114.1
Gamma, 1.4 x 10^9 + 2 Hr at 400 F	13.5	13.9	13.7	95.1	124.1	114.1
Gamma, 1.4 x 10^9/400 F	8.5	10.6	4.3	59.9	94.6	35.8
Gamma, 1.4 x 10^9/400 F + 2 Hr at 400 F	6.3	9.8	3.4	44.4	87.5	28.4
Gamma, 1.4 x 10^9/400 F + 2 Hr at 500 F	3.5	7.3	2.8	24.6	65.2	23.3
Gamma, 1.4 x 10^9/400 F + 2 Hr at 600 F	6.5	7.1	4.6	45.8	63.4	38.4

Note: Gamma exposure in ergs g^{-1}(C).

TABLE C-33. ELONGATION PROPERTIES OF NOMEX YARNS EXPOSED TO GAMMA RADIATION AND/OR ELEVATED TEMPERATURE (500 F)(76)

	Elongation, %			Elongation Retained, %		
	Natural	Int. Orange	Olive Green	Natural	Int. Orange	Olive Green
Original	14.2	11.2	12.0			
Original + 2 Hr at 500 F	10.3	11.6	7.6	72.5	103.5	63.3
Gamma, 7.0 x 10^8	11.5	14.1	13.2	81.0	125.9	110.0
Gamma, 7.0 x 10^8 + 2 Hr at 500 F	8.3	8.8	2.4	58.5	78.6	20.0
Gamma, 7.0 x 10^8/500 F	10.3	10.3	4.2	72.5	93.7	35.0
Gamma, 7.0 x 10^8/500 F + 2 Hr at 400 F	8.4	8.6	3.6	59.2	76.8	30.0
Gamma, 7.0 x 10^8/500 F + 2 Hr at 500 F	8.7	10.5	5.3	61.3	95.1	44.2
Gamma, 7.0 x 10^8/500 F + 2 Hr at 600 F	6.6	7.8	5.3	46.5	69.7	44.2
Gamma, 1.4 x 10^9	15.0	12.9	13.7	105.6	115.2	114.1
Gamma, 1.4 x 10^9 + 2 Hr at 500 F	8.8	10.5	3.7	61.8	95.1	30.8
Gamma, 1.4 x 10^9/500 F	6.4	10.8	9.6	45.1	96.4	80.8
Gamma, 1.4 x 10^9/500 F + 2 Hr at 400 F	8.6	11.4	7.7	60.6	101.8	62.2
Gamma, 1.4 x 10^9/500 F + 2 Hr at 500 F	8.8	9.9	9.6	61.8	87.5	80.8
Gamma, 1.4 x 10^9/500 F + 2 Hr at 600 F	7.3	11.0	9.0	44.4	98.2	75.0

Note: Gamma exposure in ergs g^{-1}(C).

TABLE C-34. ELONGATION PROPERTIES OF NOMEX YARNS EXPOSED TO GAMMA RADIATION AND/OR ELEVATED TEMPERATURE (600 F)(76)

	Elongation, %			Elongation Retained, %		
	Natural	Int. Orange	Olive Green	Natural	Int. Orange	Olive Green
Original	14.2	11.2	12.0			
Original + 2 Hr at 600 F	2.2	5.5	3.9	15.5	49.1	32.5
Gamma, 7.0 x 10^8	11.5	14.1	13.2	81.0	125.9	110.0
Gamma, 7.0 x 10^8 + 2 Hr at 300 F	5.1	5.7	3.8	35.9	50.9	31.7
Gamma, 7.0 x 10^8/600 F	4.5	6.8	3.4	31.8	60.7	28.3
Gamma, 7.0 x 10^8/600 F + 2 Hr at 400 F	5.3	7.6	5.0	37.3	67.8	41.7
Gamma, 7.0 x 10^8/600 F + 2 Hr at 500 F	4.8	5.2	3.4	33.8	46.4	28.3
Gamma, 7.0 x 10^8/600 F + 2 Hr at 600 F	3.1	5.9	5.2	[illegible]	[illegible]	43.3
Gamma, 1.4 x 10^9	13.5	12.9	13.7	95.1	115.2	114.1
Gamma, 1.4 x 10^9 + 2 Hr at 600 F	4.3	4.2	3.8	30.3	37.5	31.7
Gamma, 1.4 x 10^9/600 F	3.2	6.0	1.7	22.5	53.6	14.2
Gamma, 1.4 x 10^9/600 F + 2 Hr at 400 F	3.9	3.9	2.6	27.5	34.2	21.7
Gamma, 1.4 x 10^9/600 F + 2 Hr at 500 F	4.0	4.6	3.6	28.2	41.1	30.0
Gamma, 1.4 x 10^9/600 F + 2 Hr at 600 F	3.6	5.1	3.6	26.8	45.5	30.0

Note: Gamma exposure in ergs g^{-1}(C).

TABLE C-35. TEST ENVIRONMENT AND RESULTS OF STATIC TESTS: POLYURETHANE THERMAL INSULATION(7)

Material Trade Name	Test Condition	Radiation Exposure: Gamma [ergs/gm(C)]	Neutron (n/cm²): Thermal	Neutron (n/cm²): E>2.9 Mev	Neutron (n/cm²): E>8.1 Mev	Time Until Test, days	Sample Weights: Original, gm	Sample Weights: Change, gm	Compressive Strength* at 25% Deflection, psi	Temperature Average, °F	Pressure Average, (torr)
CPR-20 Compression Buttons	Air	0	0 (control specimens)	0	0	—	-	-	126 105 99 84 96 100/13		-
	Air	6.5(7)	3.5(12) (air irradiation)	1.4(13)	6.0(11)	16	-	-	123.5 86 99 85 98/21	80	-
	Air	1.5(8)	3.3(12) (air irradiation)	3.0(13)	1.1(12)	16	-	-	117 86 89 126 105/19	80	-
	Air	1.36(9)	1.8(13) (air irradiation)	2.5(14)	9.5(12)	16	-	-	89 91 91.5 124 99/17	82	-
	Air	7.5(7)	4.6(12) (vacuum irradiation)	5.2(12)	2.35(11)	7	0.6354 0.4578 0.4738 0.4554	-0.0013 -0.0010 -0.0006 -0.0006	111 82.5 85 87.5 92/14	80	1.7(-7)
	Air	1.8(8)	8.4(12) (vacuum irradiation)	1.85(13)	7.6(11)	7	0.4754 0.4724 0.4651 0.4626	-0.0011 -0.0012 -0.0009 -0.0005	91.5 86 103 114 99/14	80	1.7(-7)
	Air	9.1(8)	2.8(13) (vacuum irradiation)	1.6(14)	6.0(12)	7	0.6451 0.4722 0.4663 0.4768	-0.0026 -0.0020 -0.0025 -0.0019	116 79.5 85 80 90/18	90	4(-7)

TABLE C-35. (Concluded)

Material Trade Name	Test Condition	Radiation Exposure: Gamma ergs/gm(C)	Radiation Exposure: Neutron (n/cm²) Thermal	Neutron E>2.9 Mev	Neutron E>8 1 Mev	Time Until Test, days	Sample Weights: Original, gm	Sample Weights: Change, gm	Compressive Strength* at 25% Deflection, psi	Temperature Average, °F	Pressure Average, (torr)
CPR-1021-2 Compression Buttons		0	0 (control specimens)	0	0	—	-	-	29.8 30.8 31.1 35.5 31.5 39.5 33.0/3.8	—	--
		5.08(8) (vacuum irradiation, low force static)	8.31(12)	6.98(13)	2.77(12)	—	-	-	29.8 31.7 27.8 29.8/2.3	87	2.5(-7)
Low-Force Dynamic Test Results: Run II, June 4, 1963											
CPR-20 Compression Buttons		5.08(8)	8.31(12) (vacuum irradiation)	6.98(13)	2.77(12)	—	-	-	142.5 120.0 111.0 124.5/18.6	[illegible]	2.5(-7)
CPR-1021 Compression Buttons		5.08(8)	8.31(12) (vacuum irradiation)	6.98(13)	2.77(12)	—	-	-	50.6 48.0 [illegible] 49.4/3.6	87	2.5(-7)

* Values given as: average value/ standard deviation on an individual basis.

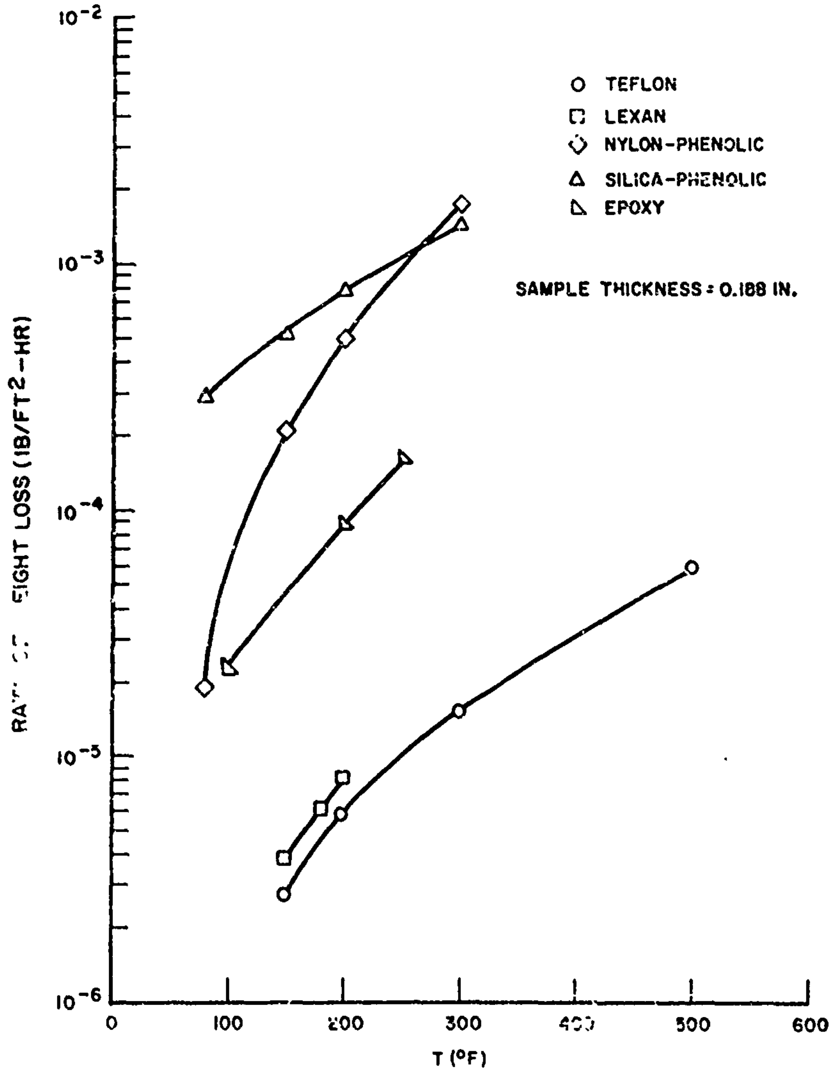

FIGURE C-1. INITIAL RATES OF WEIGHT LOSS FOR ORGANIC MATERIALS TESTED(61)

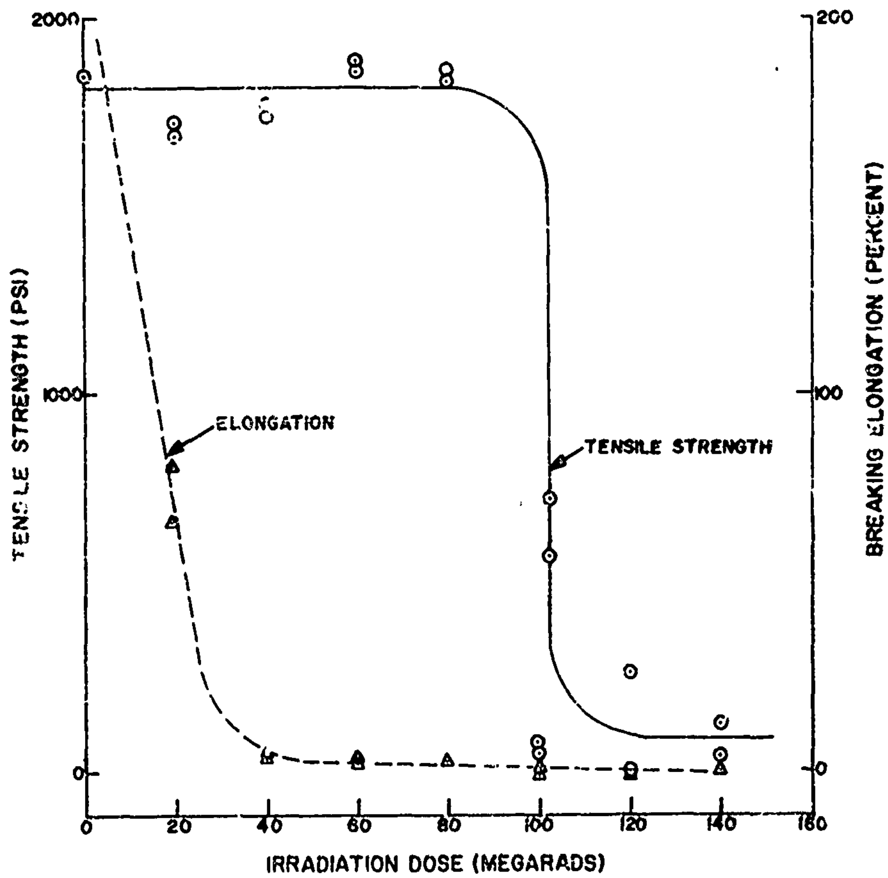

FIGURE C-2. TENSILE PROPERTIES OF IRRADIATED POLYTETRAFLUOROETHYLENE FILM (VACUUM = 10^{-6} mm Hg)[82]

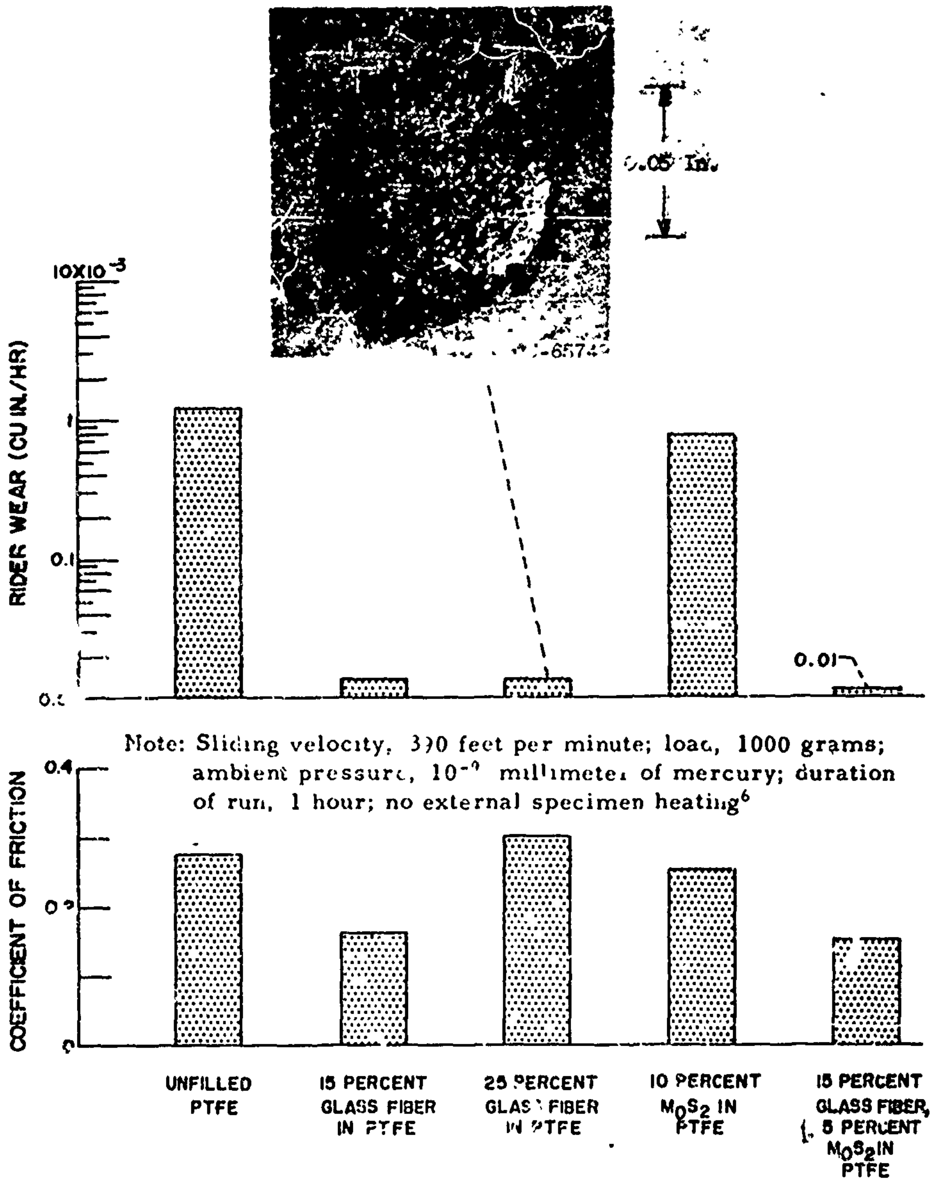

FIGURE C-3. COEFFICIENT OF FRICTION AND RIDER WEAR FOR VARIOUS POLYTETRAFLUOROETHYLENE COMPOSITIONS SLIDING ON 440-C STAINLESS STEEL IN VACUUM (10^{-9} mm Hg)

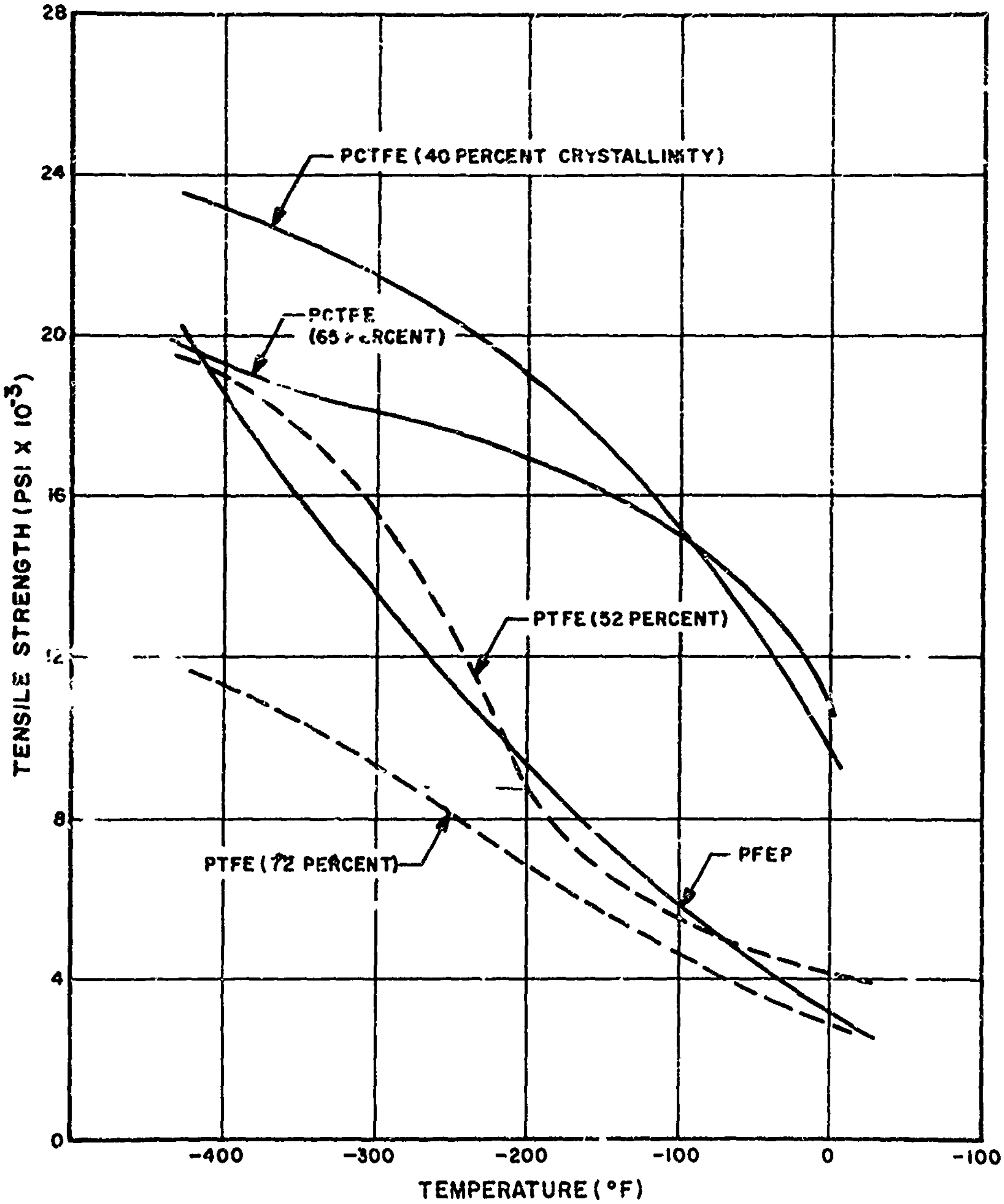

FIGURE C-4. TENSILE STRENGTH OF FLUOROCARBON PLASTICS AT CRYOGENIC TEMPERATURES(64)

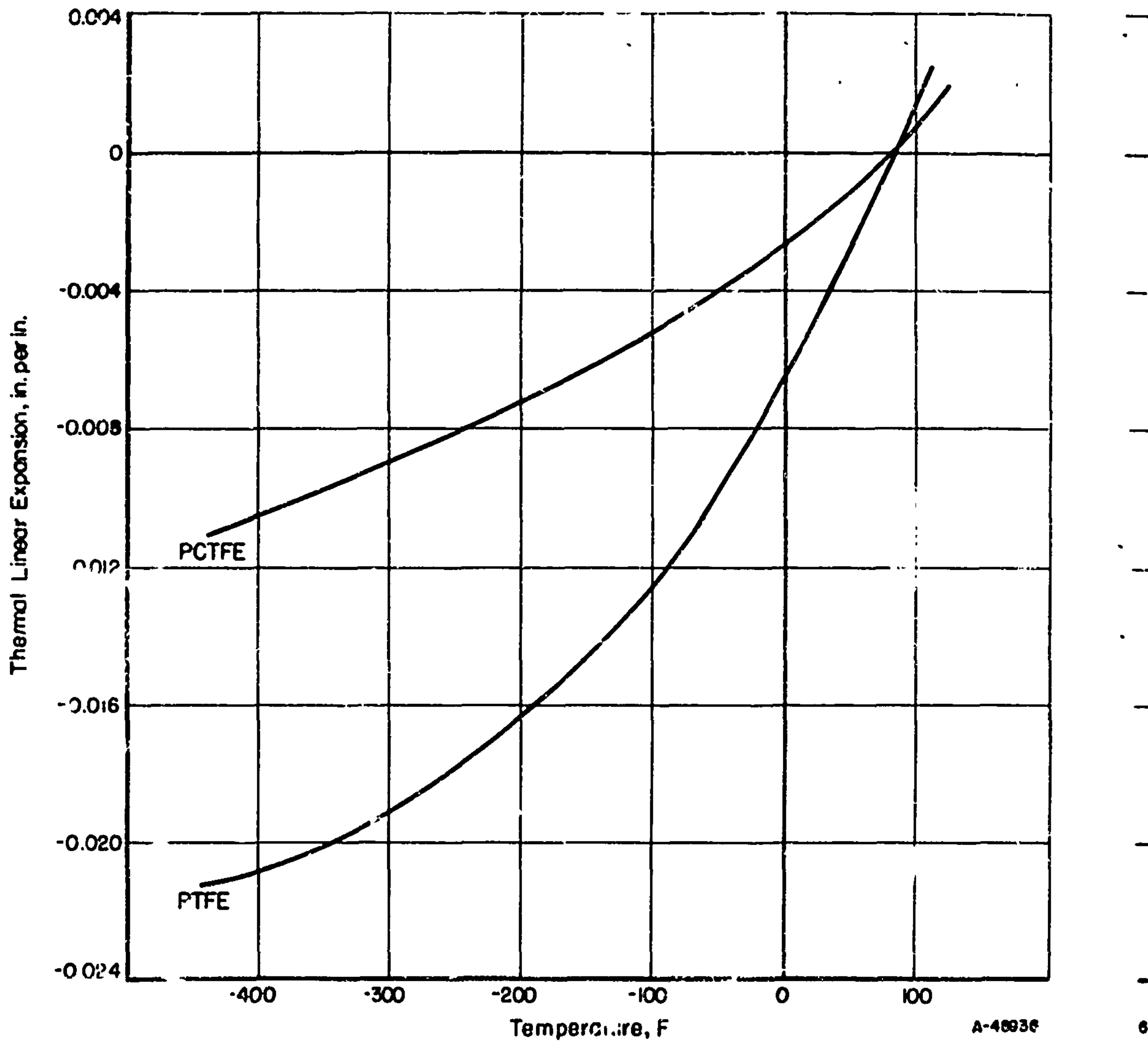

FIGURE C-5. THERMAL LINEAR EXPANSION OF PCTFE AND PTFE AT SUBZERO TEMPERATURES(69)

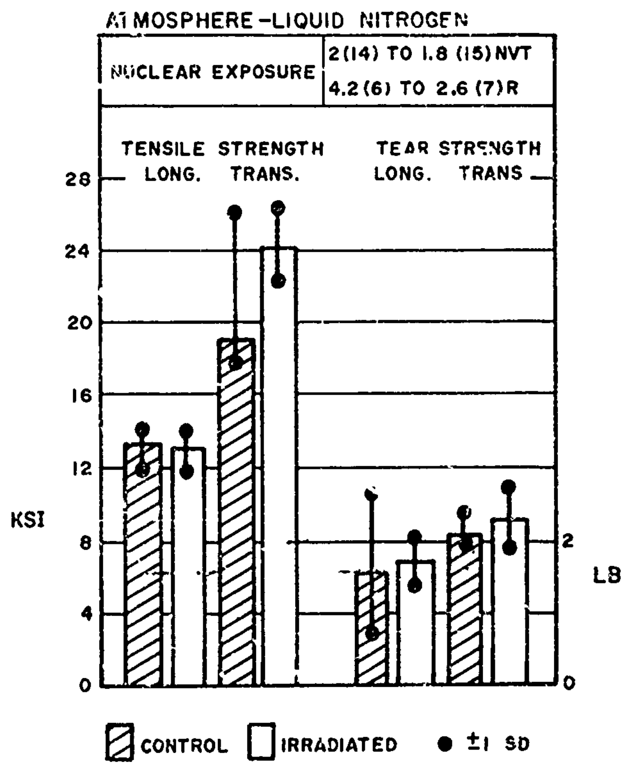

FIGURE C-6. RADIATION EFFECTS ON KEL-F FILM[13]

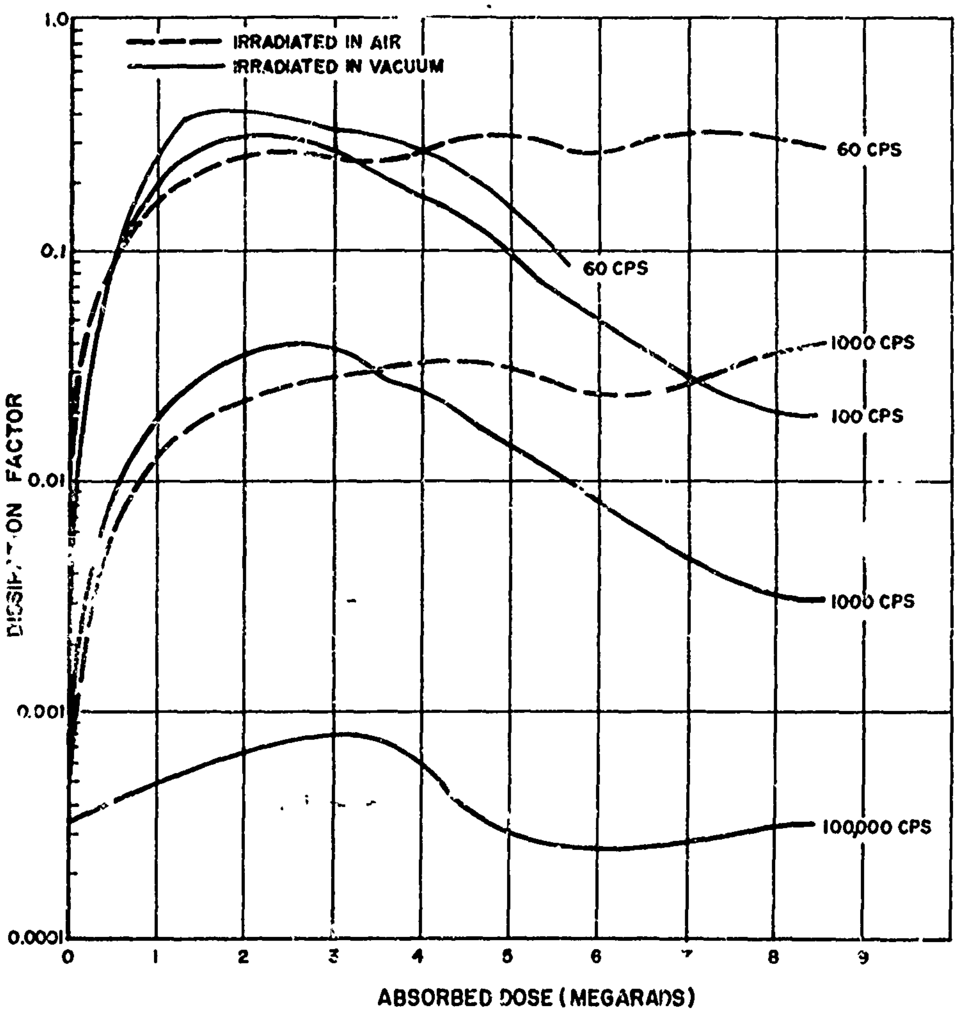

FIGURE C-7. EFFECT OF X-RAY IRRADIATION ON TFE-6 (DISSIPATION FACTOR)[63]

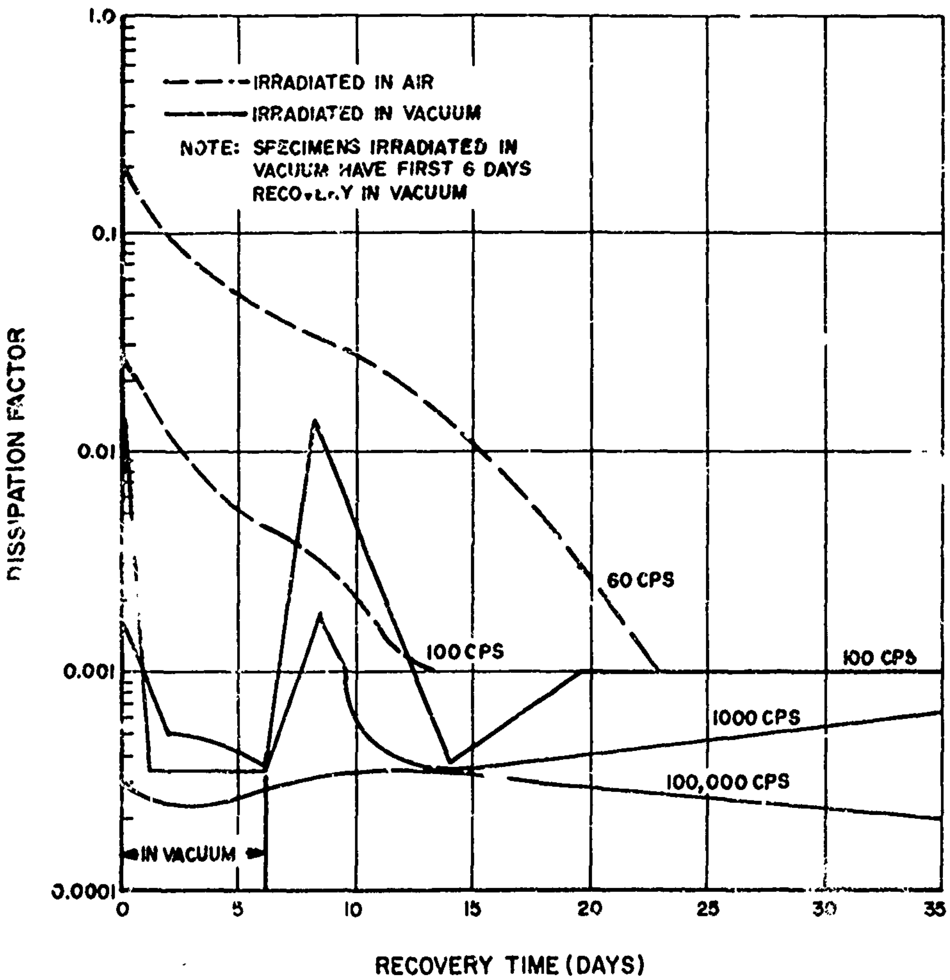

FIGURE C-8. RECOVERY CHARACTERISTICS OF TFE-6 SPECIMENS AFTER X-RAY IRRADIATION[63]

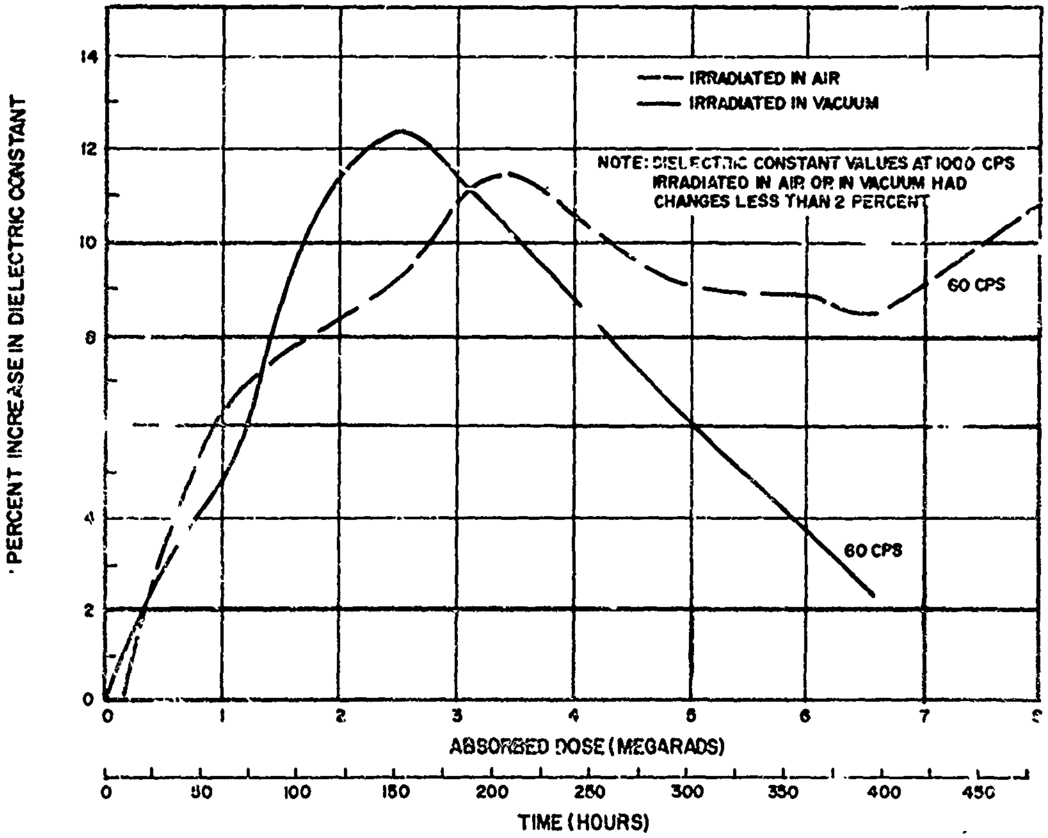

FIGURE C-9. EFFECT OF X-RAY IRRADIATION ON TFE-6 (DIELECTRIC CONSTANT)(63)

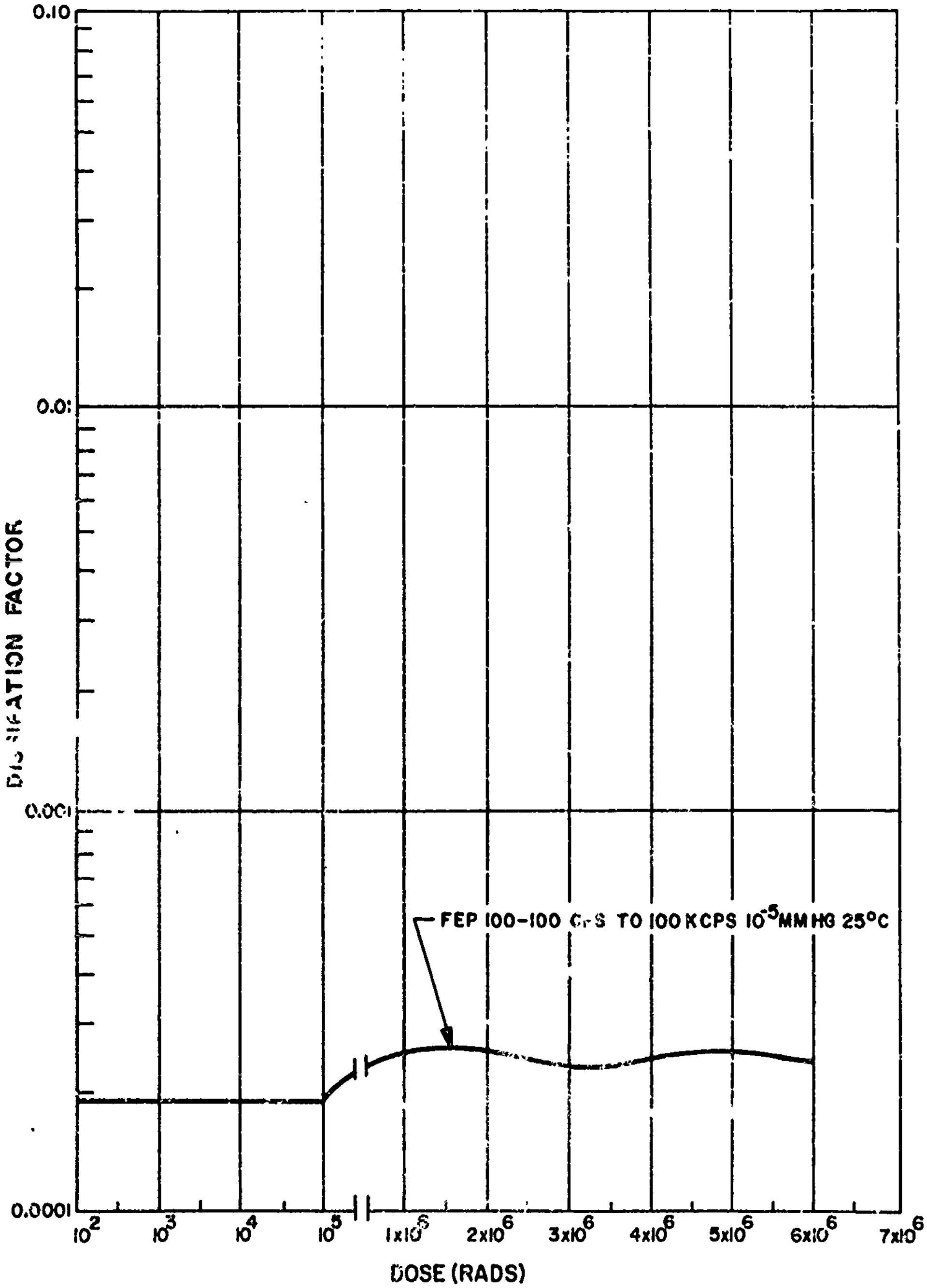

FIGURE C-10. EFFECT OF X-RAY IRRADIATION ON FEP-100 (DISSIPATION FACTOR)[63]

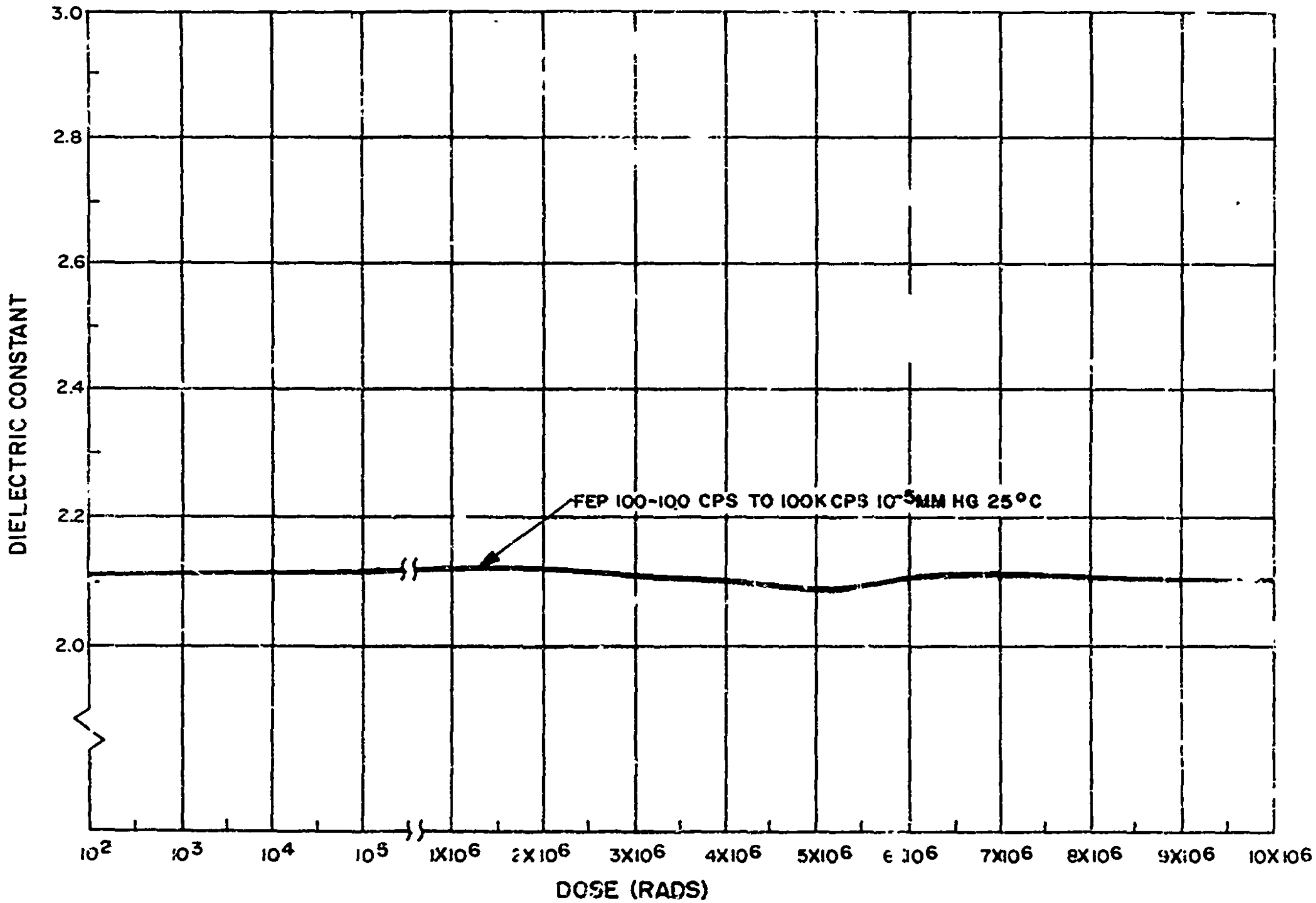

FIGURE C-11. EFFECT OF X-RAY IRRADIATION ON FEP-100 (DIELECTRIC CONSTANT)(63)

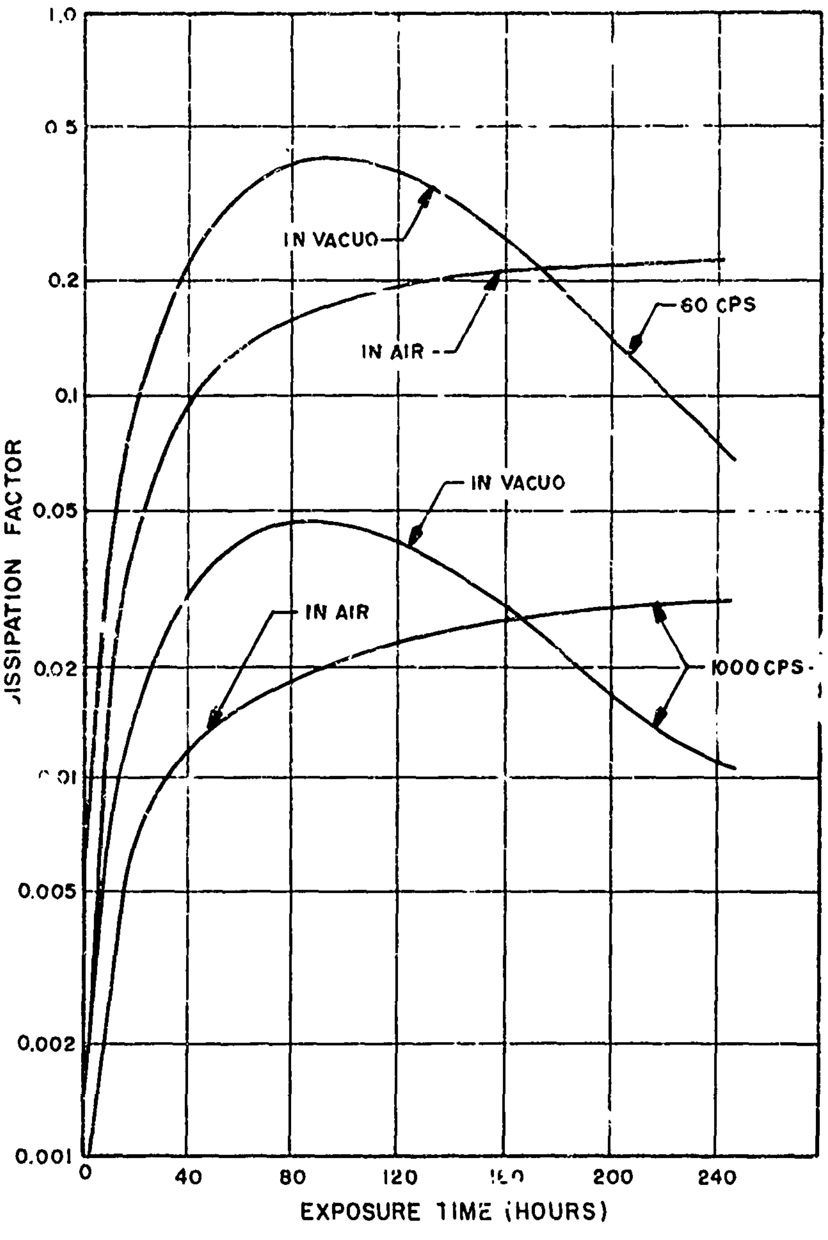

FIGURE C-12. COMPARISON OF THE EFFECTS OF X-IRRADIATION ON THE DISSIPATION FACTOR OF PTFE-6 IN VACUO (5×10^{-6} mm Hg) AND IN AIR[64]

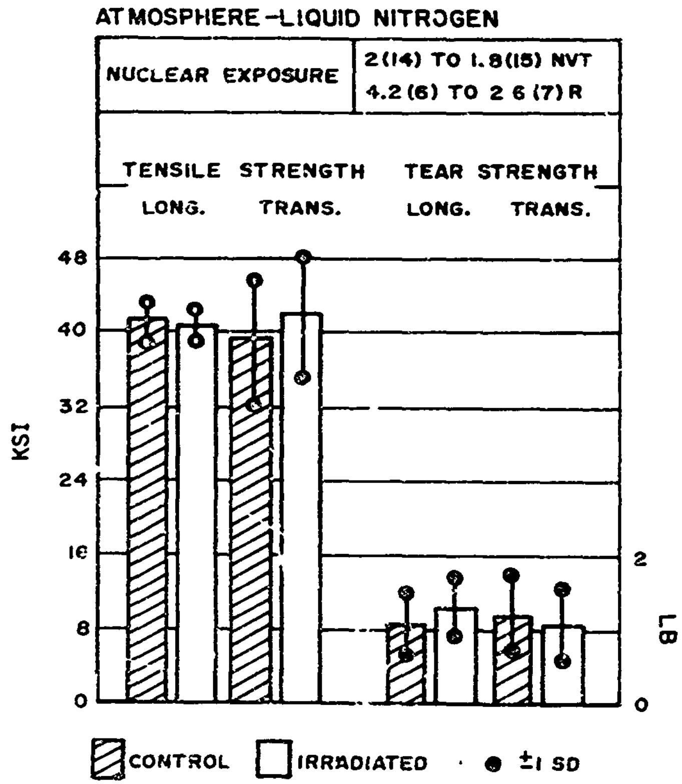

FIGURE C-13. RADIATION EFFECTS ON MYLAR FILM(13)

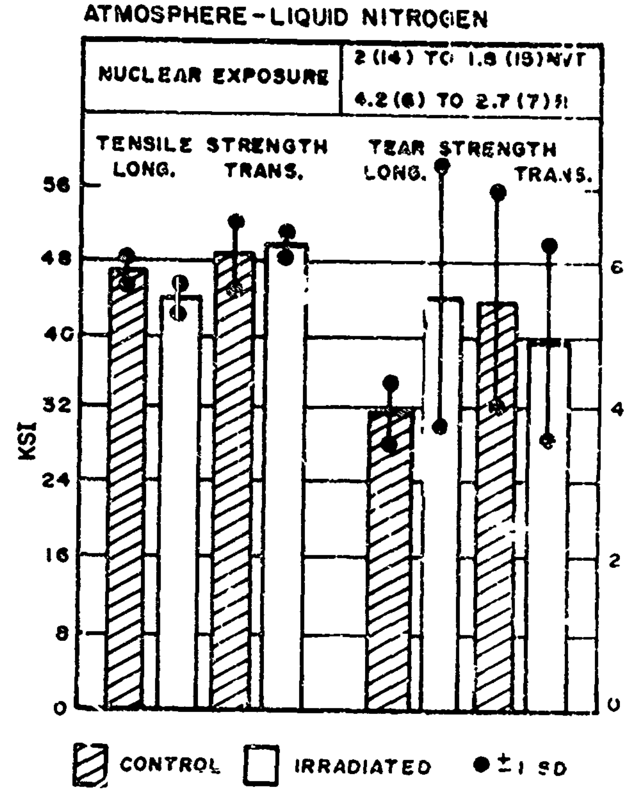

FIGURE C-14. RADIATION EFFECTS ON ALUMINIZED MYLAR FILM(13)

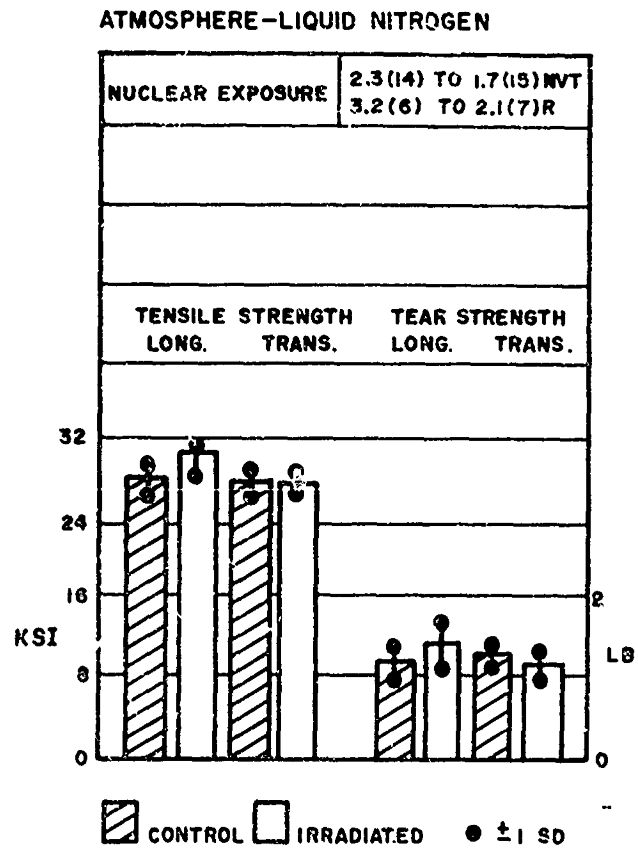

FIGURE C-15. RADIATION EFFECTS ON ALUMISEAL FILM[13]
(Mylar-Aluminum-Mylar Laminate)

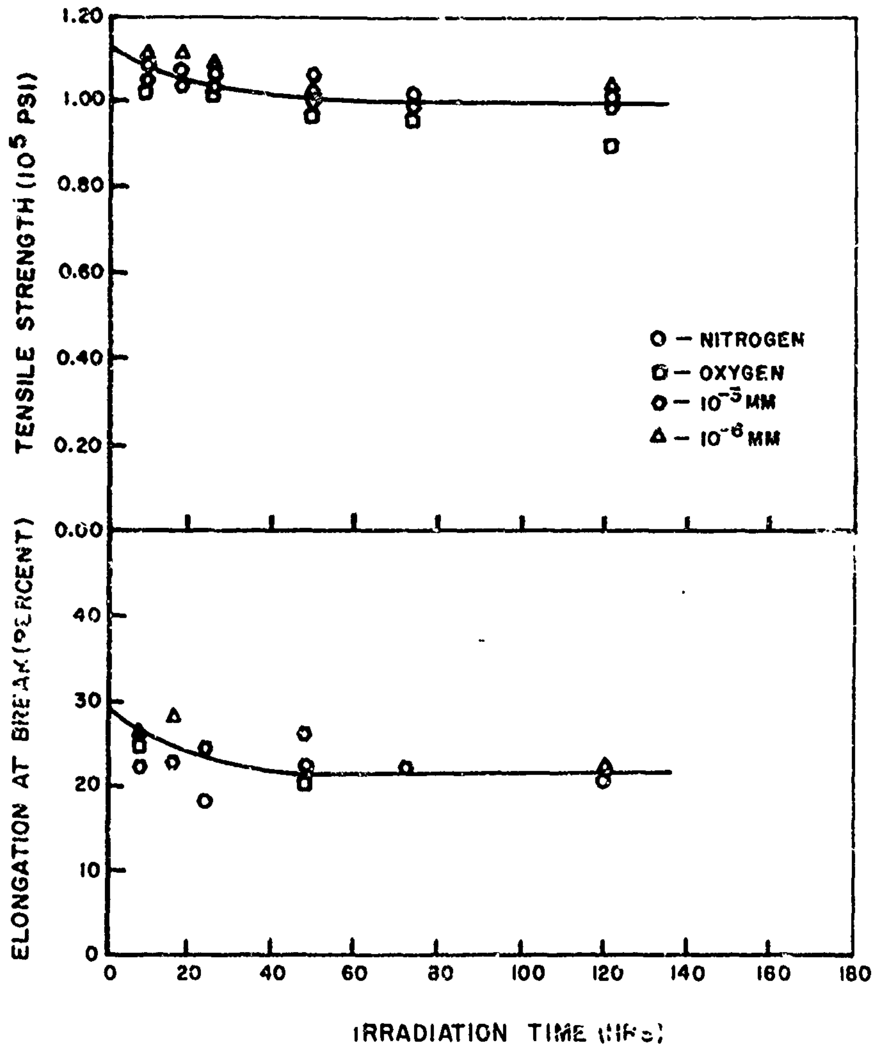

FIGURE C-16. EFFECTS ON TENSILE PROPERTIES OF HT-1 FIBERS BY IRRADIATION IN VARIOUS ENVIRONMENTS WITH 253.7 mμ LIGHT(77)

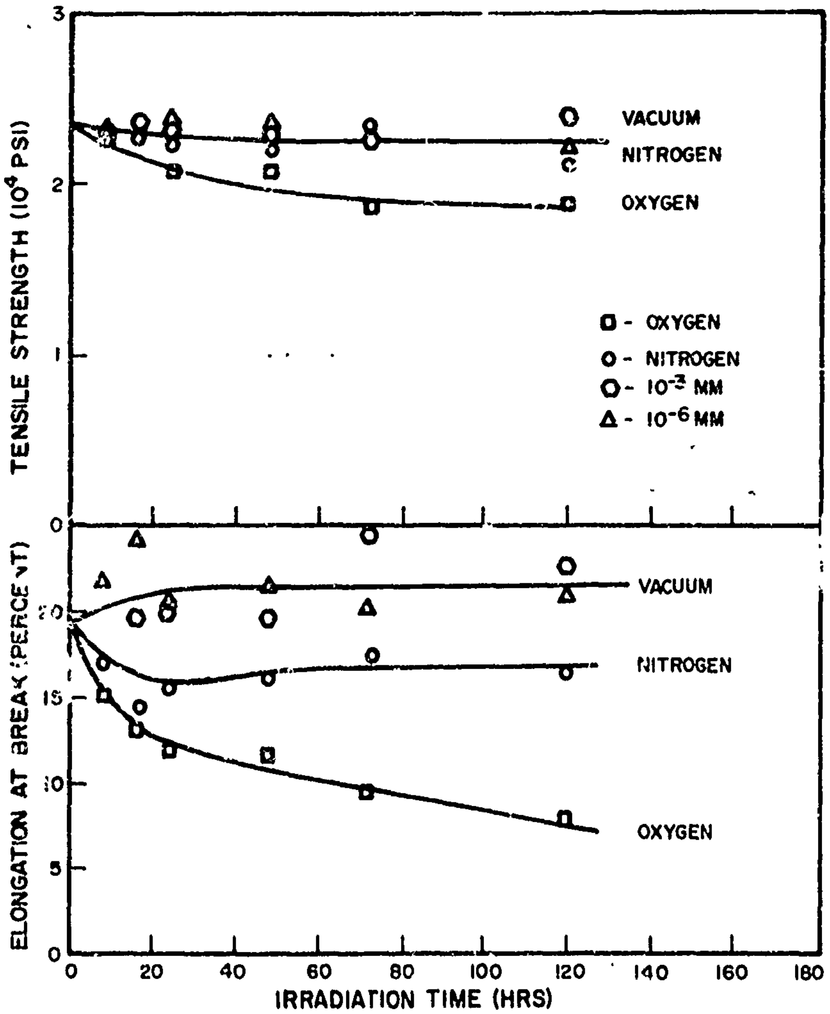

FIGURE C-17. EFFECTS ON TENSILE PROPERTIES OF POLYBENZIMIDAZOLE FIBERS BY IRRADIATION IN VARIOUS ENVIRONMENTS WITH 253.7-mμ LIGHT(77)

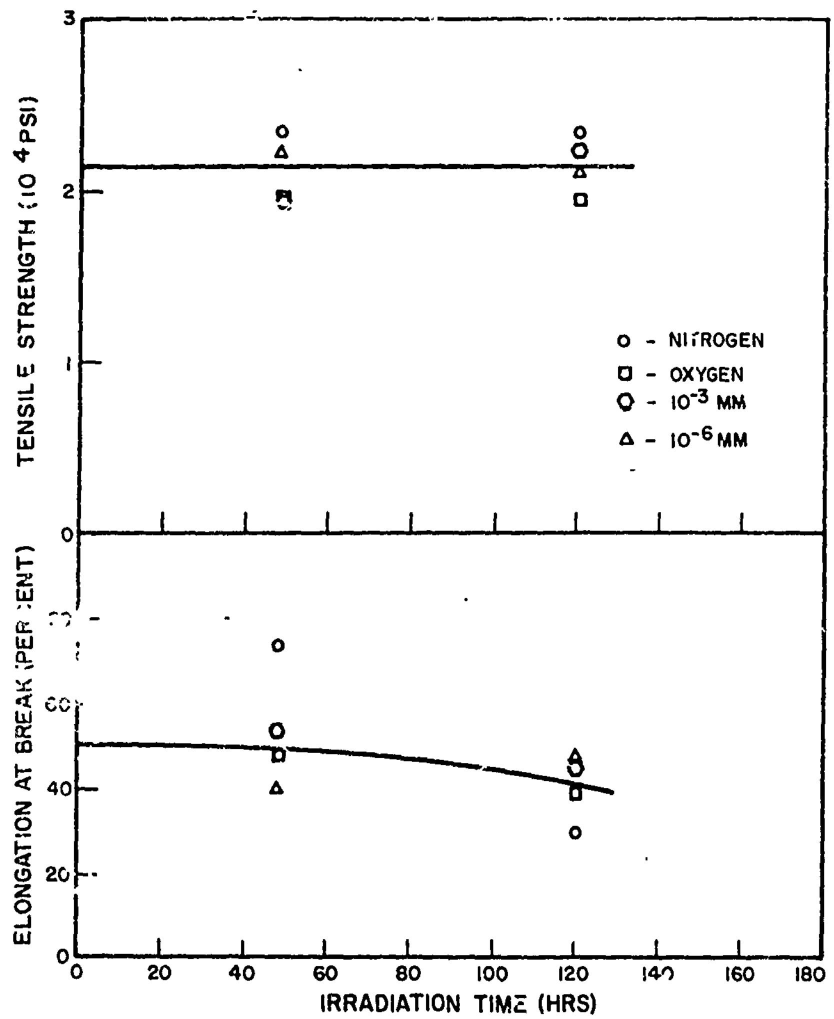

FIGURE C-18. EFFECTS ON TENSILE PROPERTIES OF FIBERS OF THIAZOLE POLYMER BY IRRADIATION IN VARIOUS ATMOSPHERES WITH 253.7-mμ LIGHT[77]

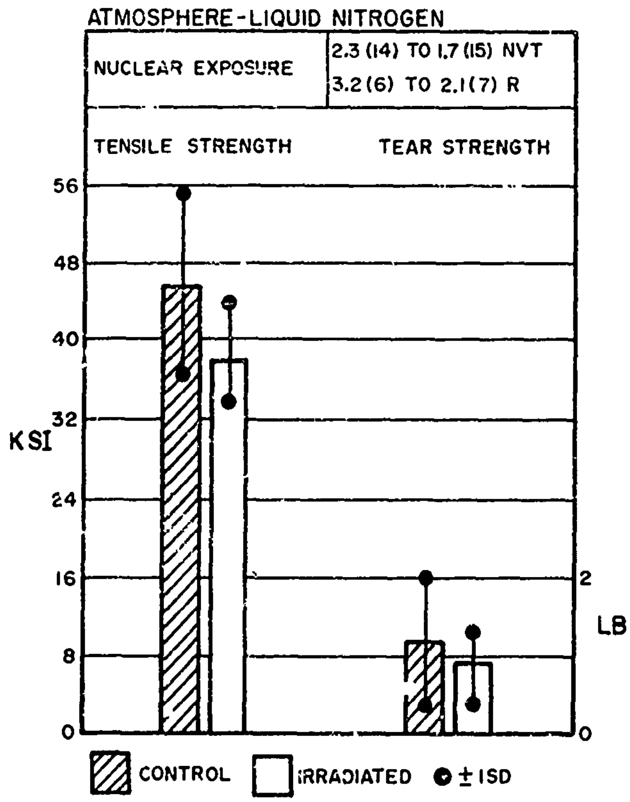

FIGURE C-19. RADIATION EFFECTS ON DUPONT "H" FILM(13)

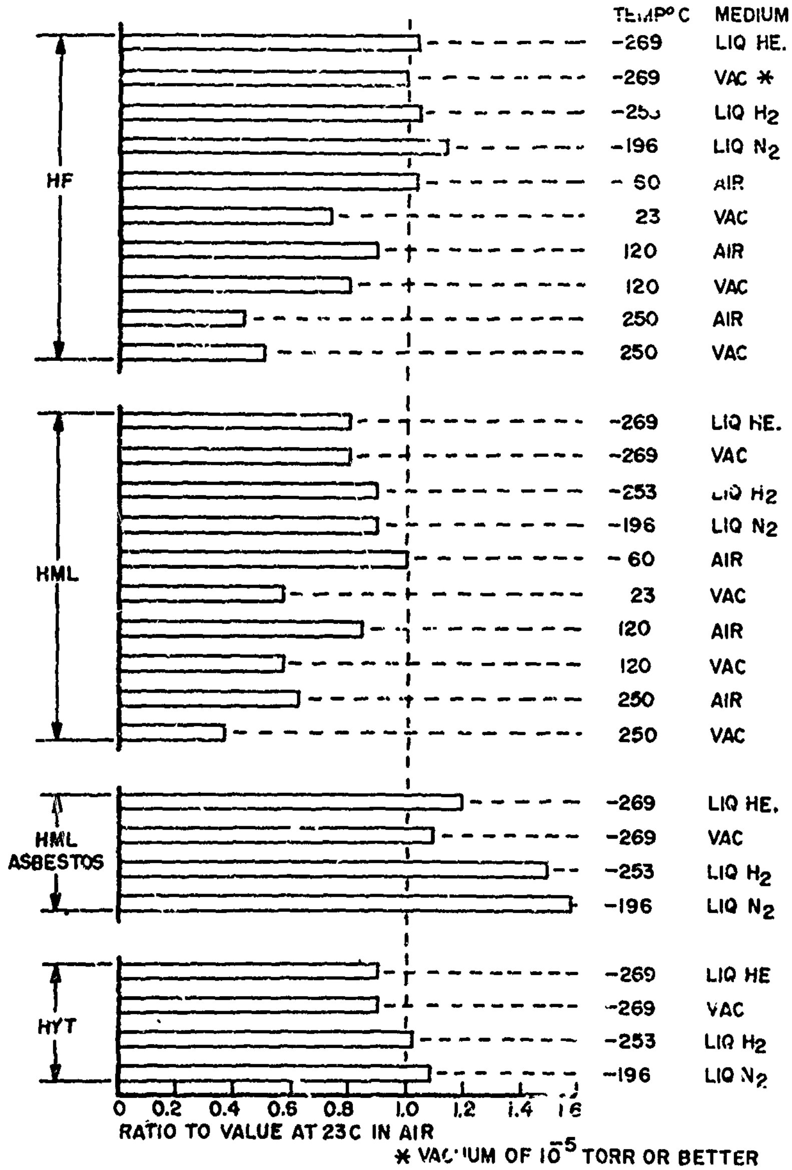

FIGURE C-20. COMPARISON OF BREAKDOWN VOLTAGE UNDER DIFFERENT TEST AMBIENTS FOR FILM-COATED WIRES(78)

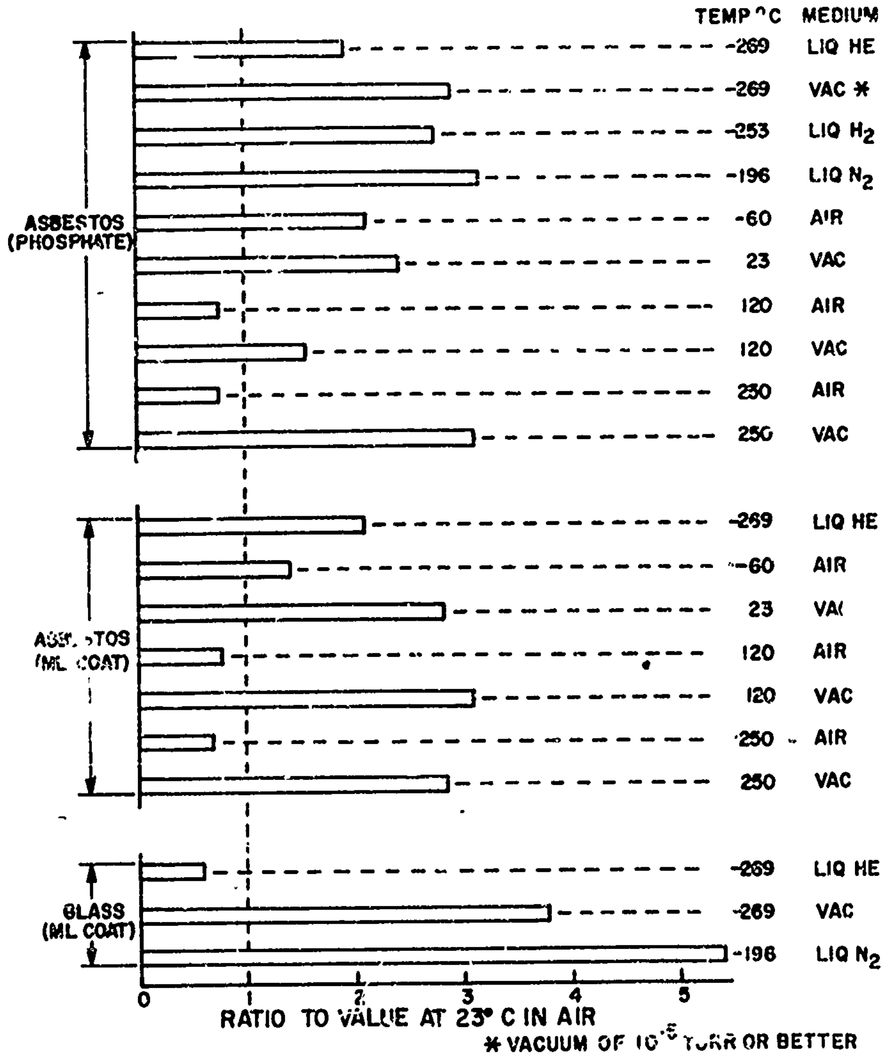

FIGURE C-21. COMPARISON OF BREAKDOWN VOLTAGE UNDER DIFFERENT TEST AMBIENTS FOR FIBROUS-COATED WIRES(78)

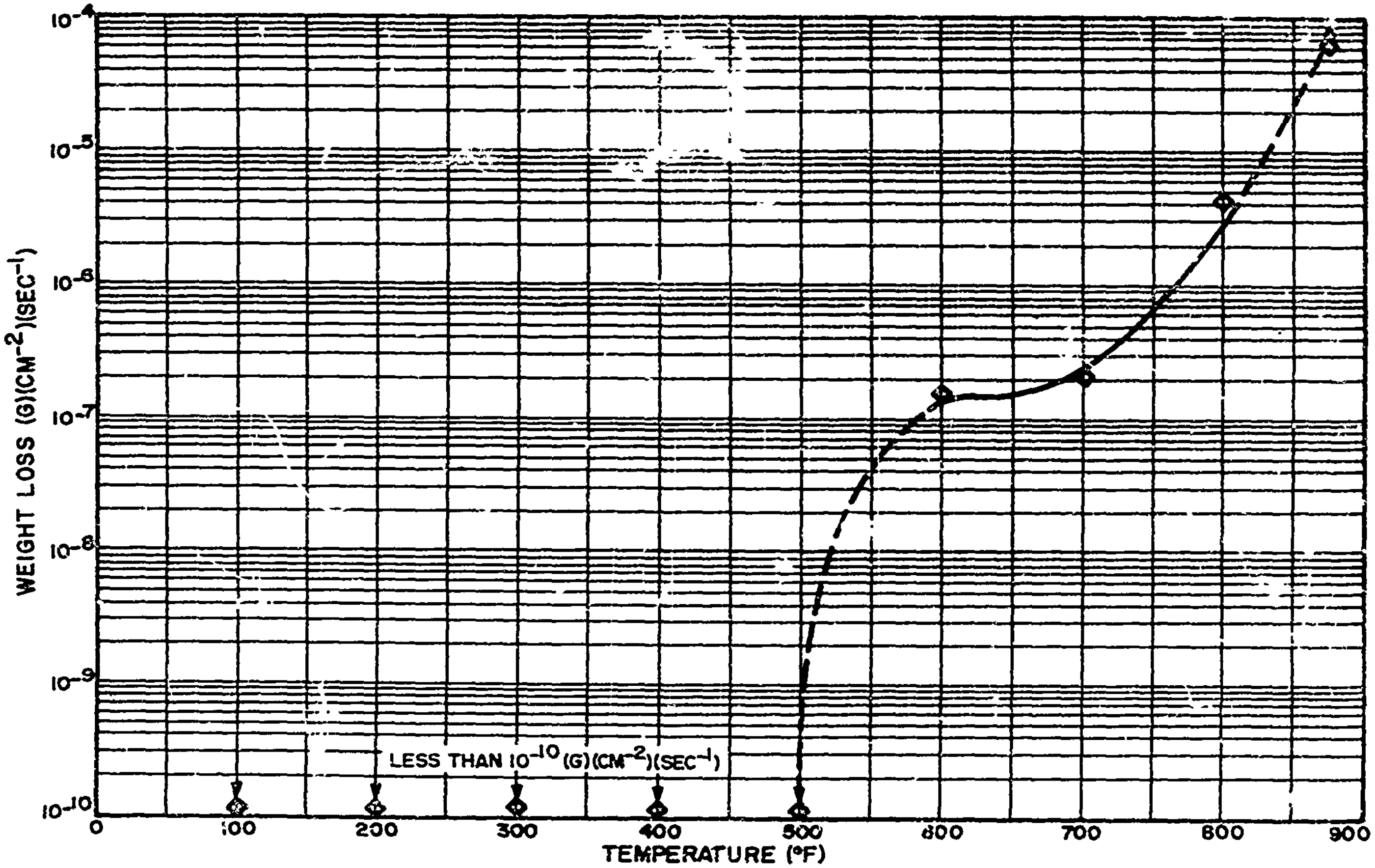

FIGURE C-22. WEIGHT LOSS OF POLYIMIDE IN VACUUM AS A FUNCTION OF SPECIMEN TEMPERATURE, AMBIENT PRESSURE, 10^{-7} TO 10^{-8} MILLIMETER OF MERCURY(65)

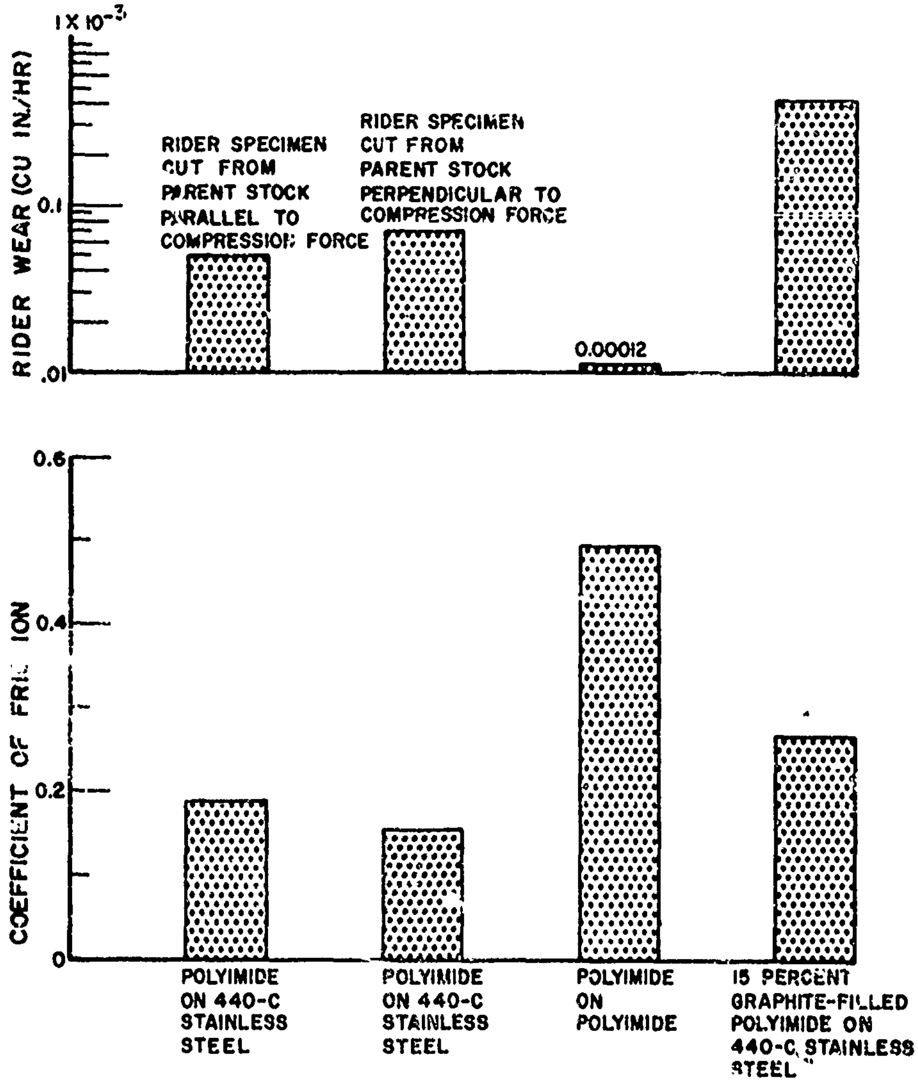

FIGURE C-23. COEFFICIENT OF FRICTION AND RIDER WEAR FOR VARIOUS MATERIAL COMBINATIONS IN VACUUM (10^{-9} mm Hg)

Note: Sliding velocity, 390 feet per minute; load, 1000 grams; duration of run, 1 hour; no external specimen heating(65)

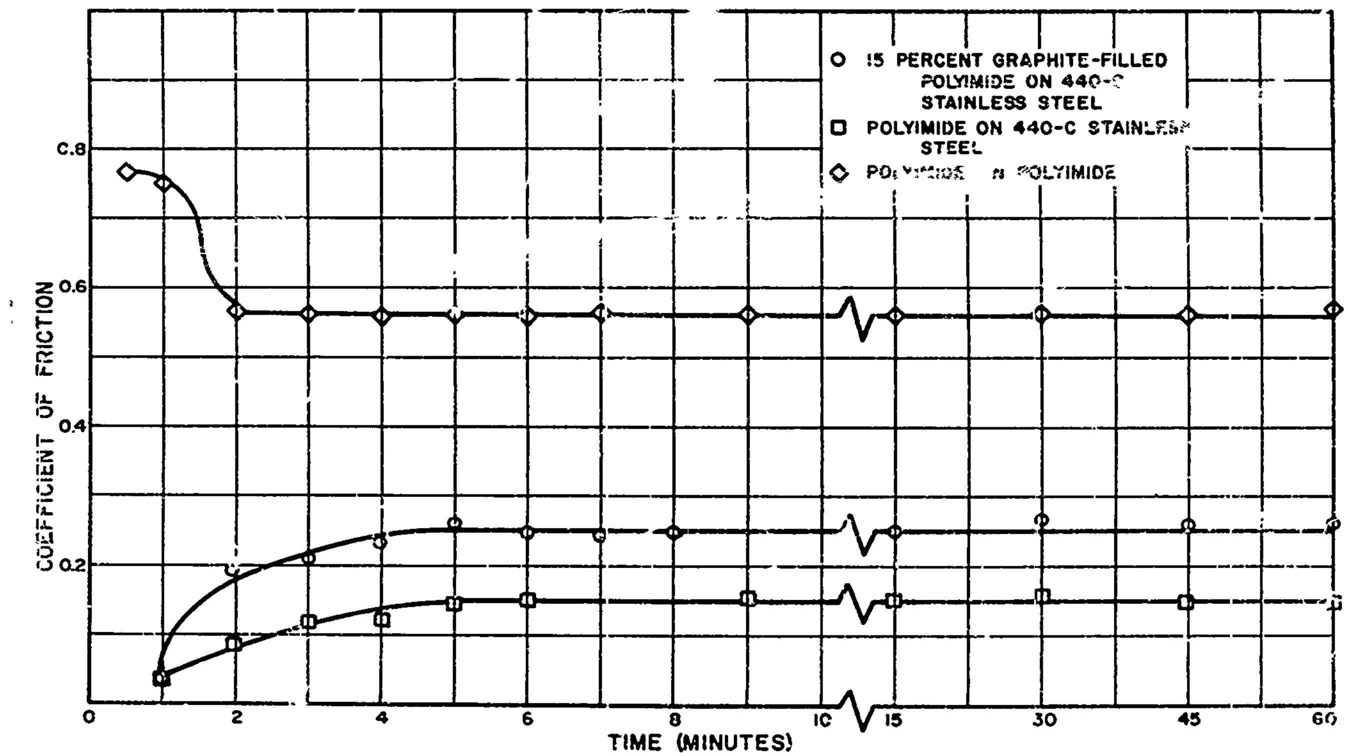

FIGURE C-24. COEFFICIENT OF FRICTION AS A FUNCTION OF TIME FOR POLYIMIDE SLIDING ON POLYIMIDE AND ON 440-C STAINLESS STEEL IN VACUUM (10^{-9} mm Hg)

Note: Sliding velocity, 390 feet per minute, load, 1000 grams; ambient pressure, 10^{-9} millimeter of mercury; no external specimen heating.[65]

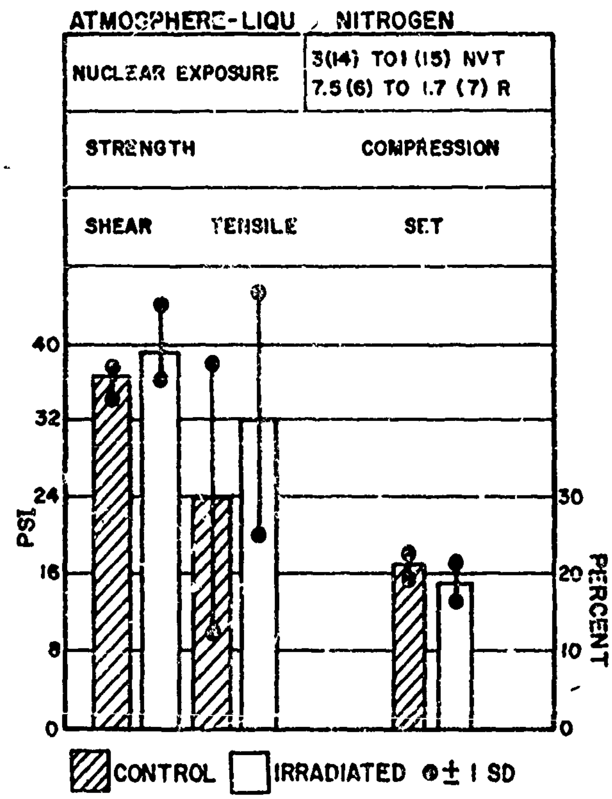

FIGURE C-25. RADIATION EFFECTS ON MAGNOLIA FOAM(13)

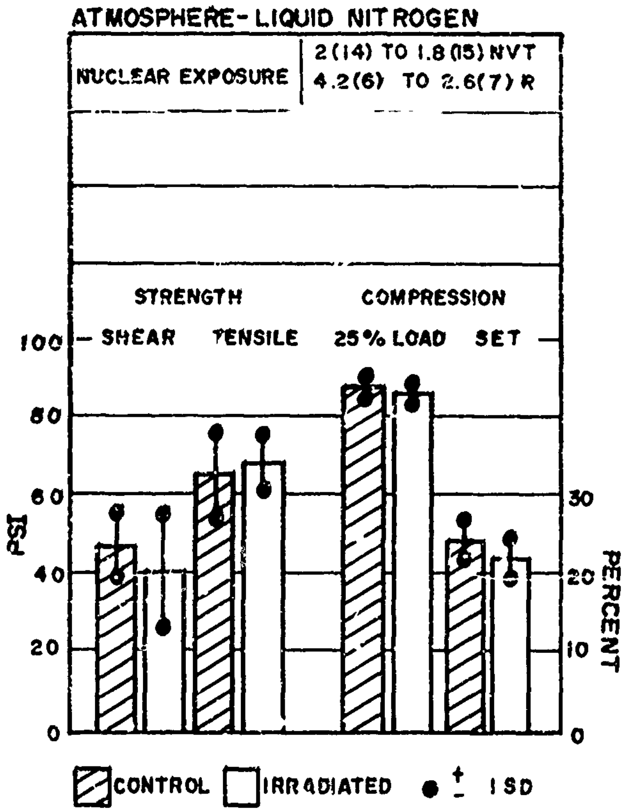

FIGURE C-26. RADIATION EFFECTS ON MARFOAM(13)

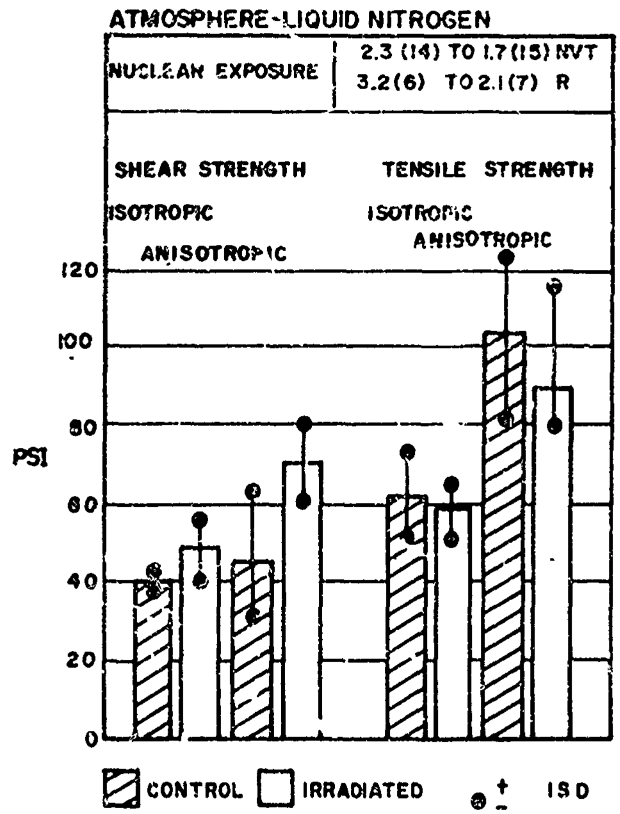

FIGURE C-27. RADIATION EFFECTS ON SHEAR AND TENSILE STRENGTHS OF CPR20-3 FOAM[13]

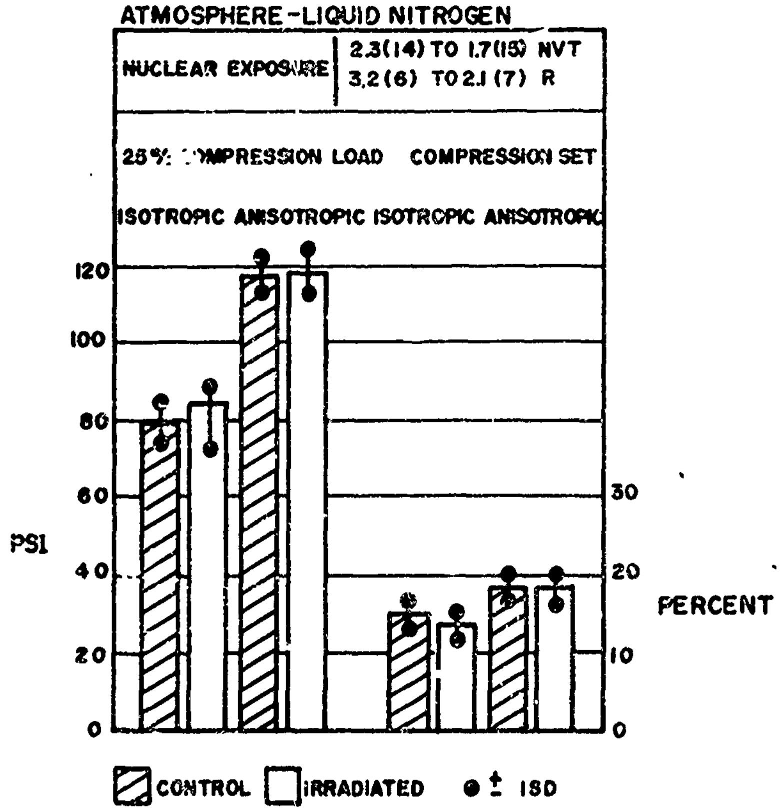

FIGURE C-26. RADIATION EFFECTS ON COMPRESSIVE PROPERTIES OF CPR20-3 FOAM[13]

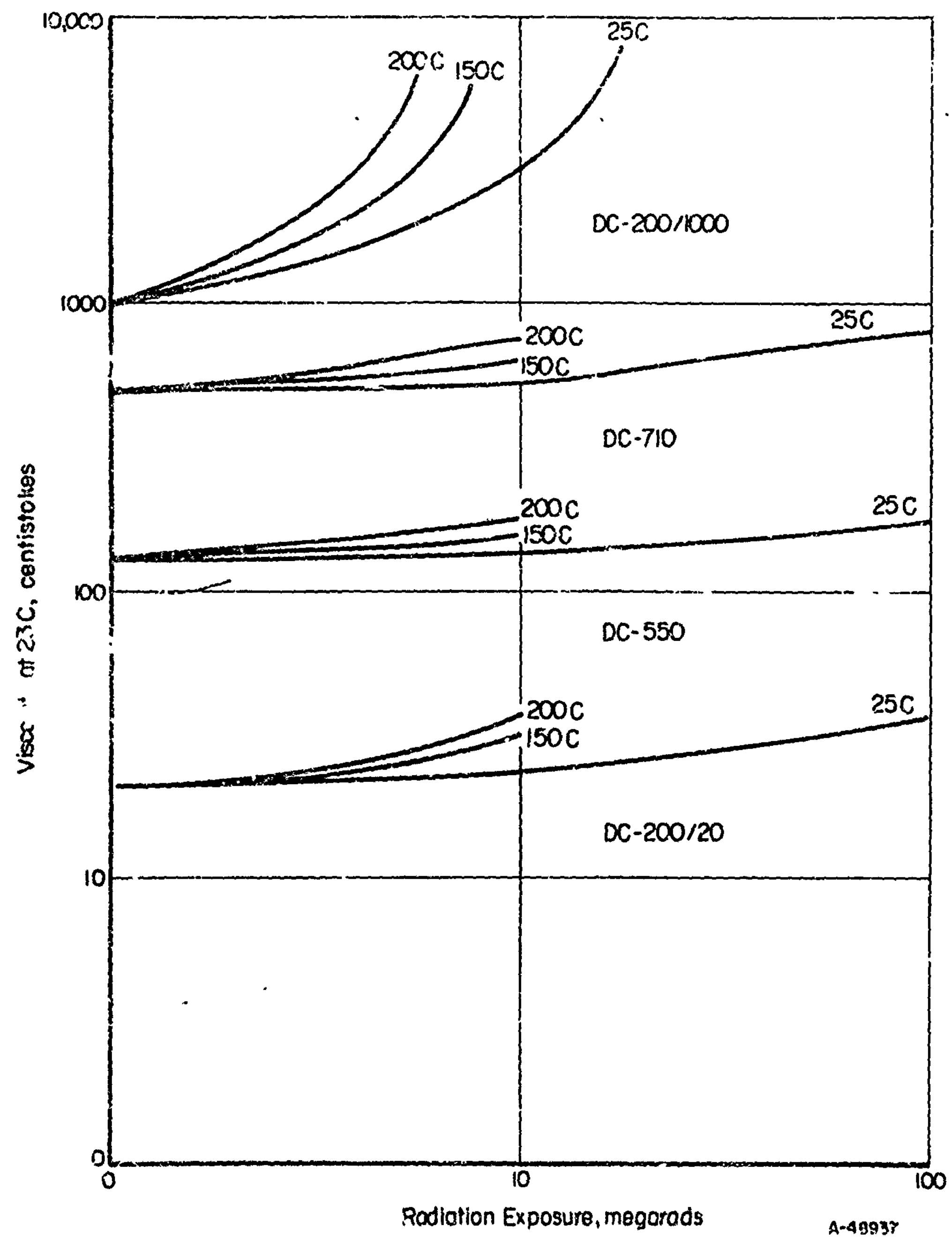

FIGURE C-29. EFFECTS OF GAMMA RADIATION ON VISCOSITY OF SILICONE FLUIDS(36)

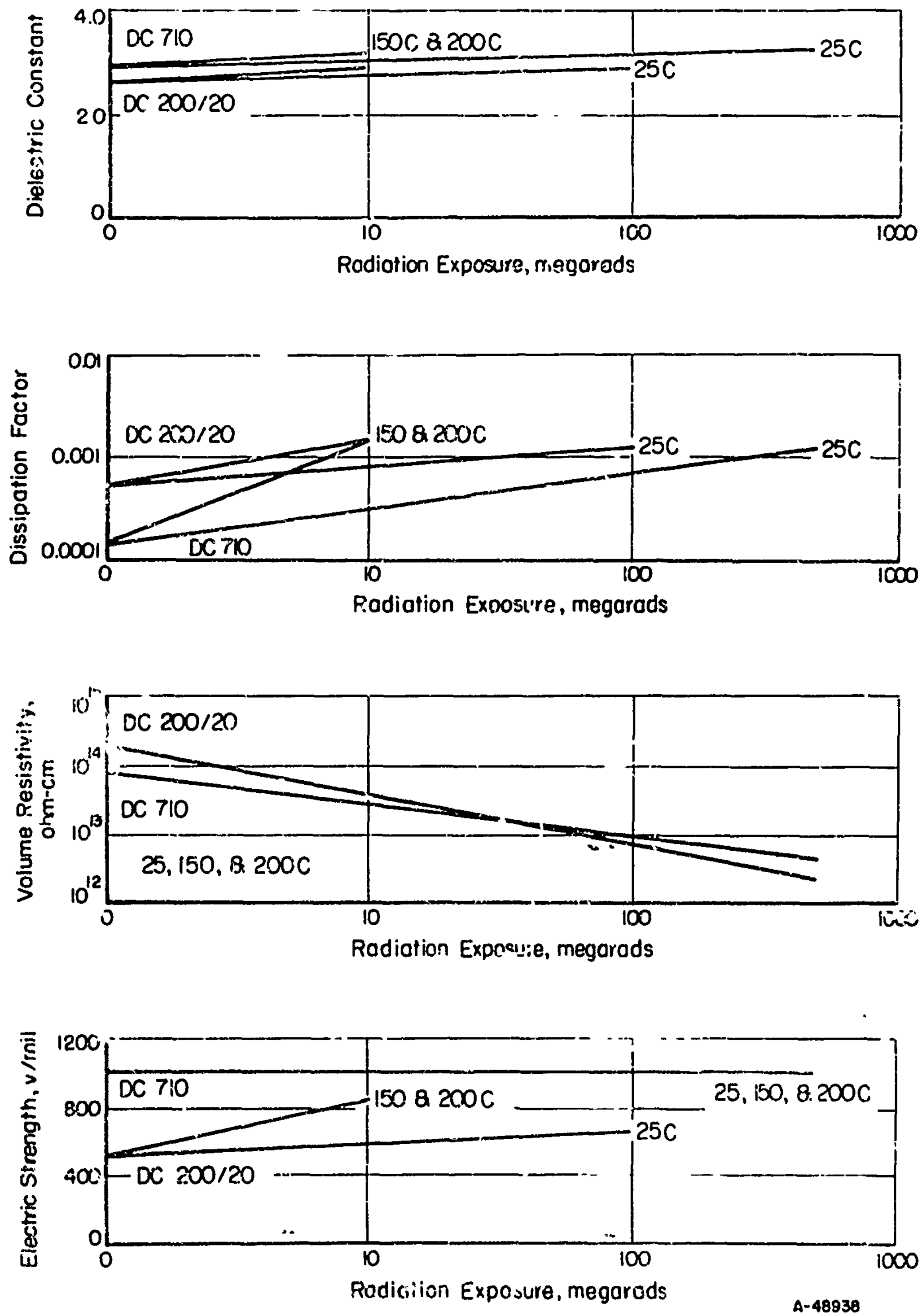

FIGURE C-30. EFFECTS OF GAMMA RADIATION ON ELECTRICAL PROPERTIES OF SILICONE FLUIDS(36)

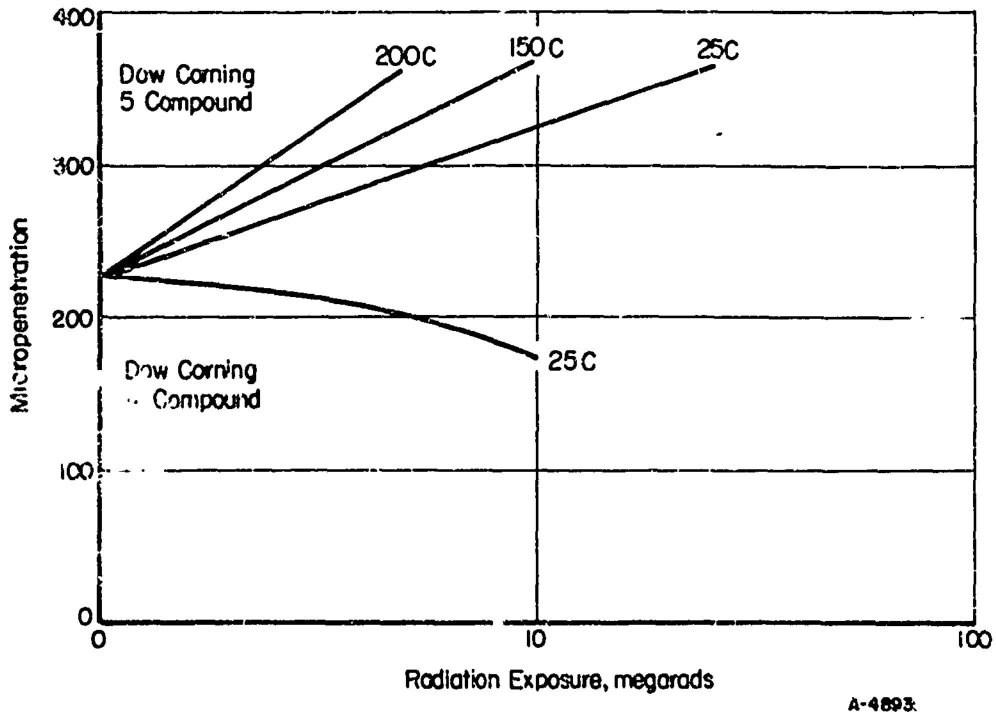

FIGURE C-31. EFFECTS OF GAMMA RADIATION ON PENETRATION OF SILICONE COMPOUNDS[36]

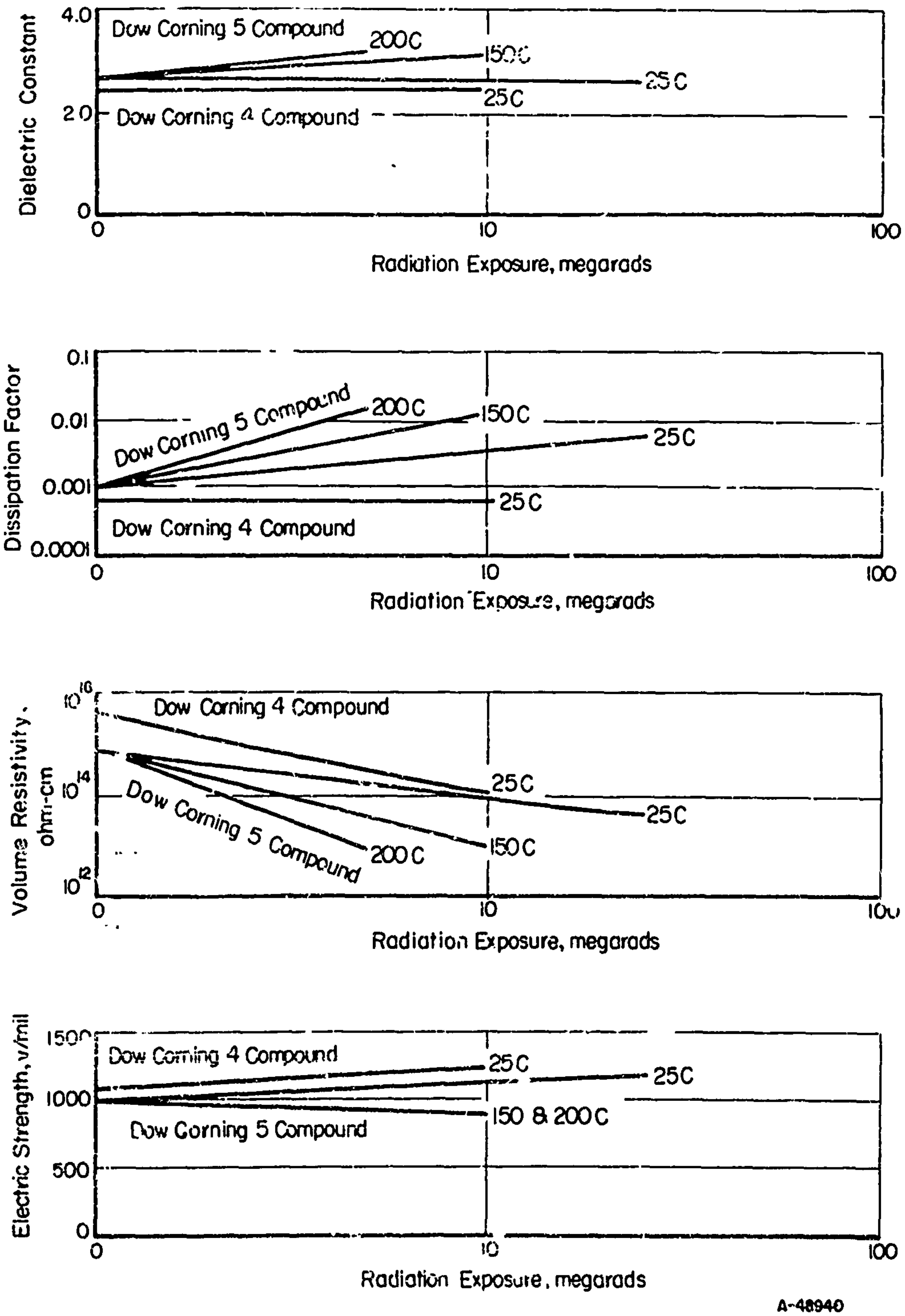

FIGURE C-32. EFFECTS OF GAMMA RADIATION ON ELECTRICAL PROPERTIES OF SILICONE COMPOUNDS(36)

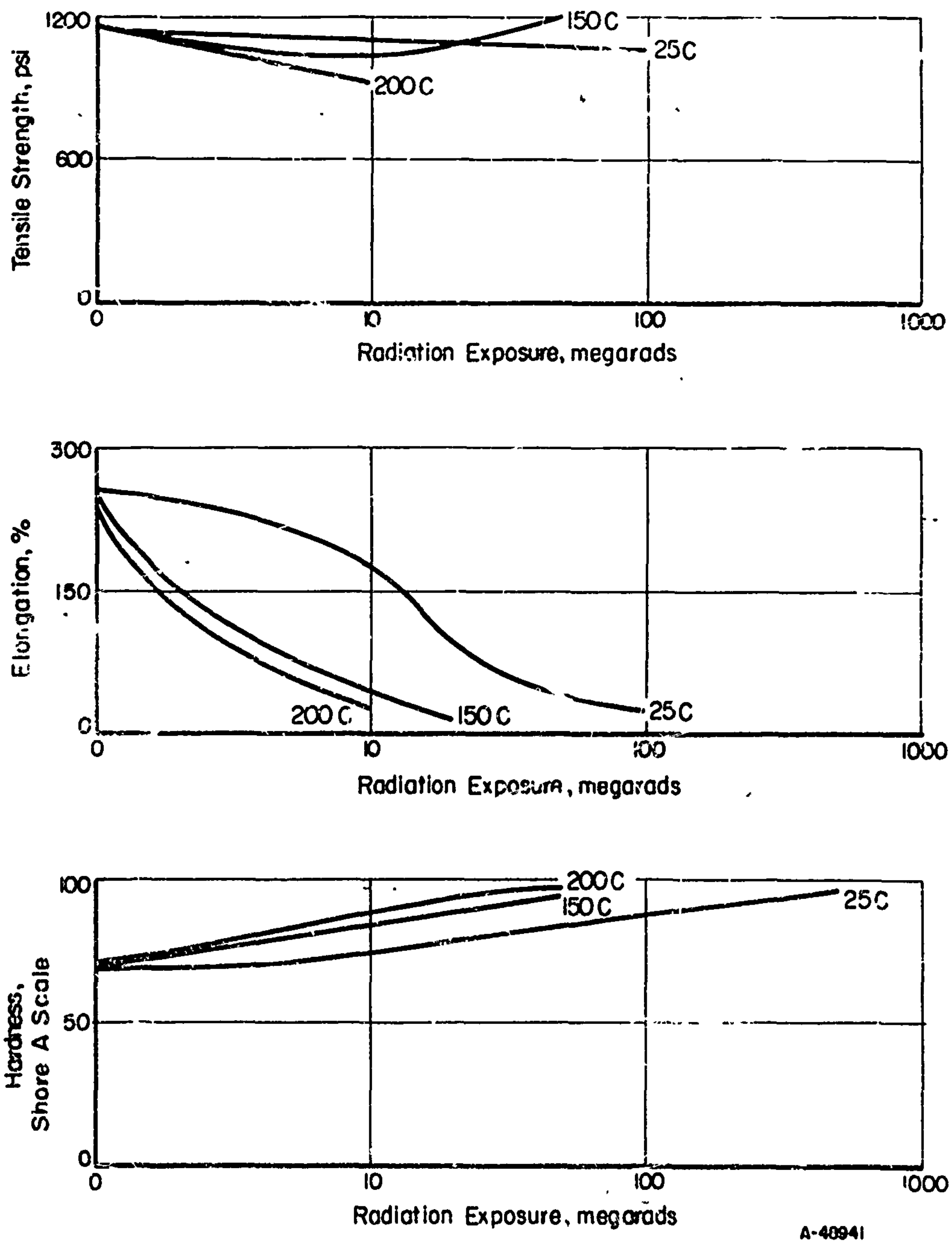

FIGURE C-33. EFFECTS OF GAMMA RADIATION ON PHYSICAL PROPERTIES OF SILASTIC 1602[36]

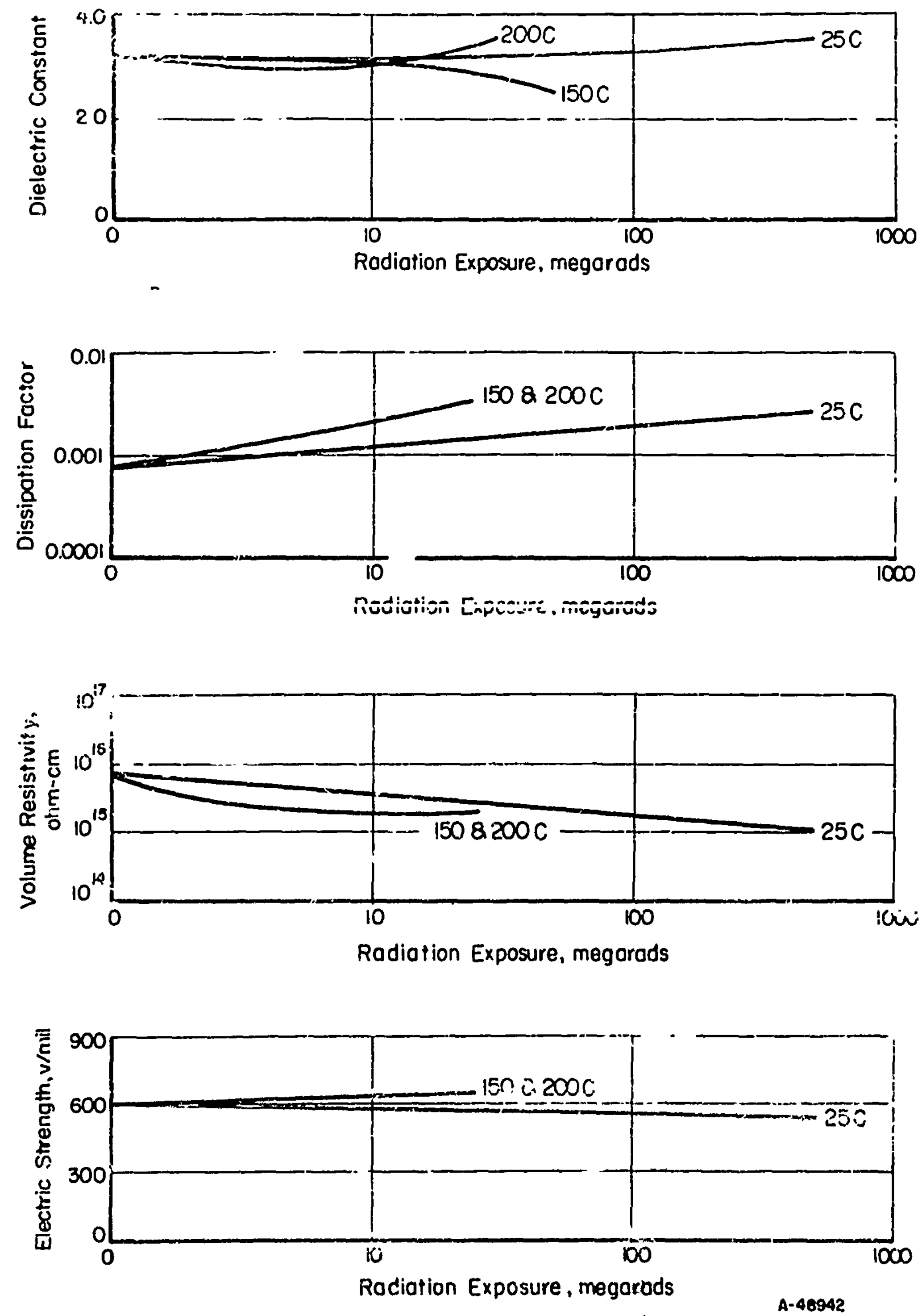

FIGURE C-34. EFFECTS OF GAMMA RADIATION ON ELECTRICAL PROPERTIES OF SILASTIC 1602[36]

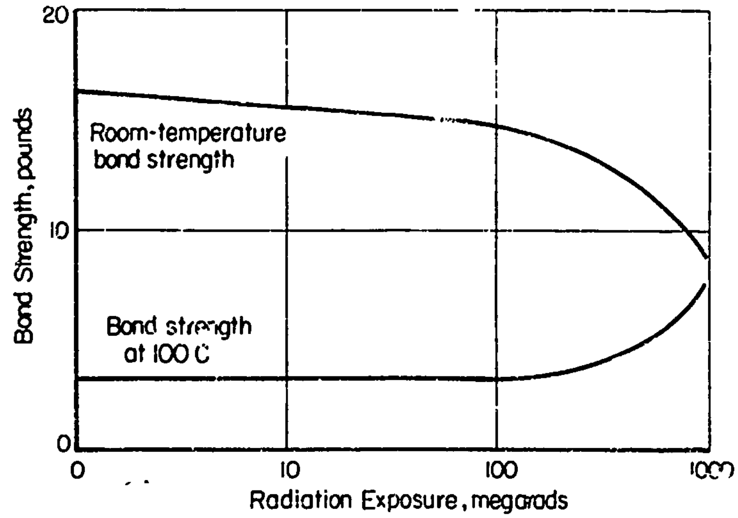

FIGURE C-35. EFFECTS OF GAMMA RADIATION ON BOND STRENGTH OF DOW CORNING 980 VARNISH(36)

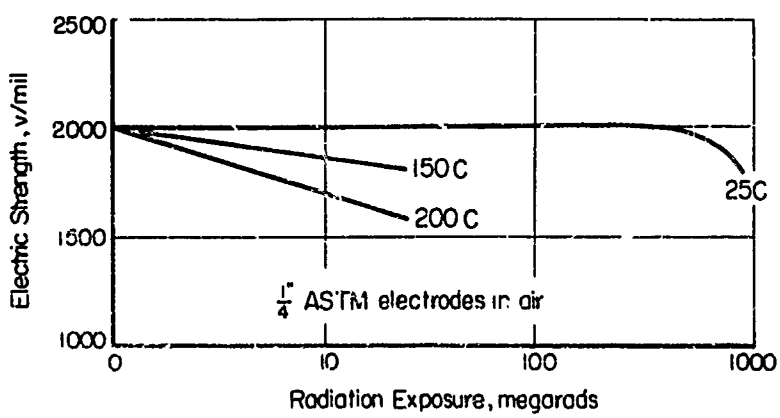

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FIGURE C-36. EFFECTS OF GAMMA RADIATION ON ELECTRIC STRENGTH OF DOW CORNING 980 VARNISH(36)

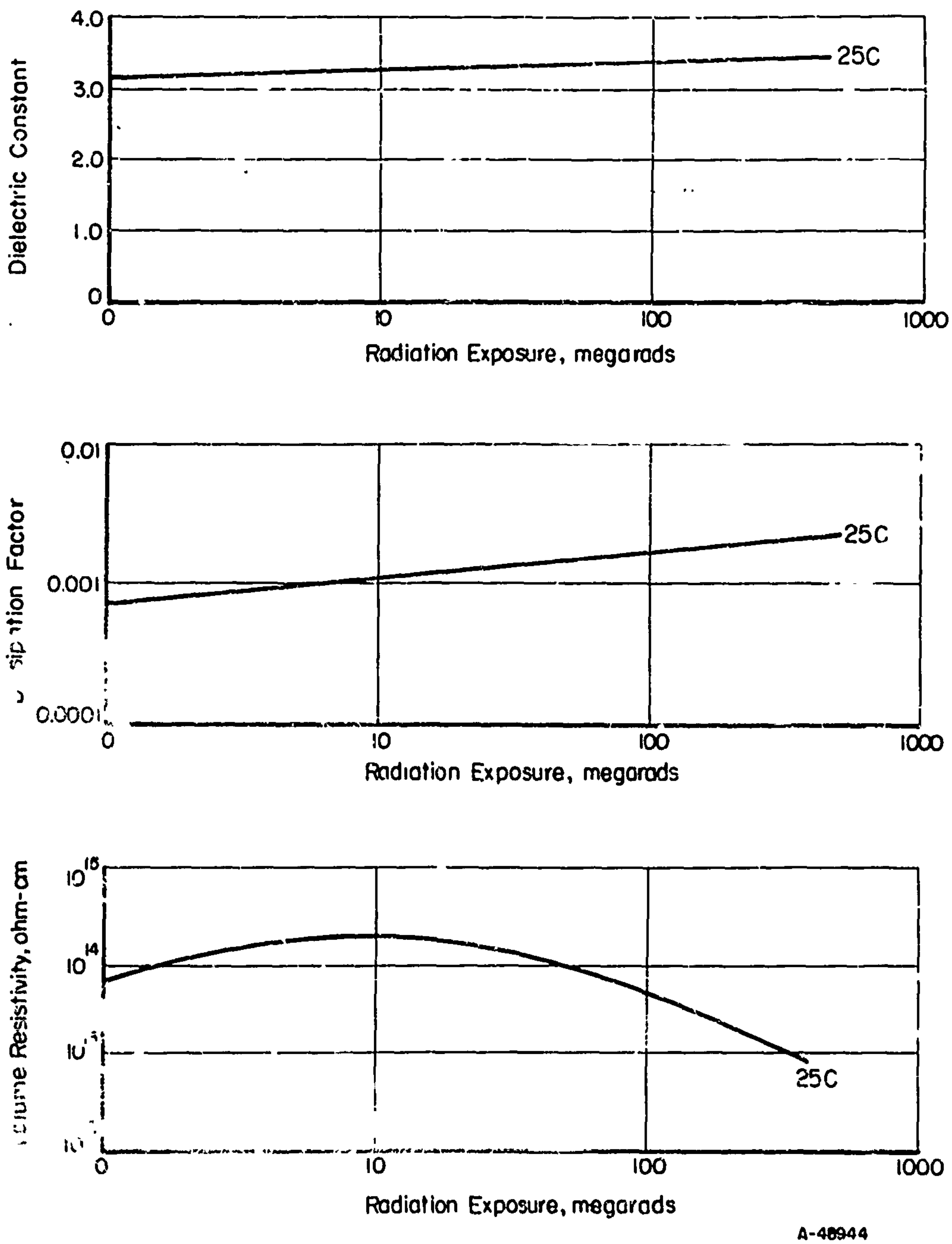

FIGURE C-37. EFFECTS OF GAMMA RADIATION ON ELECTRICAL PROPERTIES OF SYLGARD 182(36)

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1 (First Addendum)	The Effect of Nuclear Radiation on Semiconductor Materials (March 31, 1959), AD 210758
*6	A Survey of Current Research and Developments in the Field of Dosimetry (May 31, 1958), AD 157173
6 (First Addendum)	A Survey of Current Research and Developments in the Field of Dosimetry (March 31, 19[illegible]) AD 210766
10	The Effect of Nuclear Radiation on Semiconductor Devices (April 20, 1960), AD 240433 (Supersedes Memos Nos. 4, 5, 6)
10 (First Addendum)	The Effect of Nuclear Radiation on Semiconductor Devices (July 15, 1961), AD 262081
16	Survey of Irradiation Facilities (February 28, 1961), AD 256953
17	The Effect of Nuclear Radiation on Structural Adhesives (March 1, 1961), AD 256954 (Supersedes Reports Nos. 7 and 11)
18	The Effect of Nuclear Radiation on Electronic Components (June 1, 1961), AD 260303 (Supersedes Reports Nos. 8, 12, 14, and 15 and Memos Nos. 2, 7, 12, 14, and 20)
19	The Effect of Nuclear Radiation on Lubricants and Hydraulic Fluids (May 31, 1961), AD 261278 (Supersedes Report No. 4)
20	The Effect of Nuclear Radiation on Structural Metals (September 15, 1961), AD 265839 (Supersedes Report No. 5)
21	The Effect of Nuclear Radiation on Elastomeric and Plastic Components and Materials (September 1, 1961) AD 267890 (Supersedes Reports Nos. 3, 9, and 13 and Memos Nos. 1, 3, 8, 13, and 17)
23	Proton and Electron Damage to Solar Cells (April 1, 1962)
24	Radiation Effects State of the Art 1961-1962 (June 30, 1962), NASA N62-16454
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26	Transient Radiation Effects on Electronic Components and Semiconductor Devices (April 30, 1963)
27	The Effect of Nuclear Radiation on Ceramic Reactor-Fuel Materials (June 30, 1963)
28	Radiation-Effects State of the Art 1962-1963 (June 30, 1963)
29	Effect of Nuclear Radiation on Metallic Fuel Materials (September 30, 1963)
30	Effect of Nuclear Radiation at Cryogenic Temperature on Semiconductor Materials (September 30, 1963)
31	Part I. A Survey of Irradiation Facilities (September 30, 1963) Part II. A Survey of Particle Accelerators (September 30, 1963)
32	Space Radiation Damage to Electronic Components and Materials (September 30, 1963)
33	Survey of Current Research and Developments in the Field of Dosimetry (September 30, 1963)

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10	Format for Reporting Radiation Effects Data (May 15, 1959) AD 218251
*11	The Effect of Nuclear Radiation on Hydrocarbon Fuels (November 30, 1958) AD 207702

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*15	The Effect of Nuclear Radiation on Hoses and Couplings (March 31, 1959) AD 225504
*16	The Effect of Nuclear Radiation on Refrigerants (June 30, 1959) AD 21[illegible]
*18	The Effect of Nuclear Radiation on the Performance of a Hydraulic Flight Control System (June 15, 1959) AD 219512
21	Space Radiation and Its Effects on Materials (June 30, 1961)
23	Radiation Dosimetry: An Annotated Bibliography (September 15, 1961)
24	A Selected Bibliography of Pulsed Radiation Effects (June 1. 1963)
25	The Beneficial Uses of Radiation Effects

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13. ABSTRACT

This report is an addendum to REIC Report No. 21 and presents the state of the art of the effects of nuclear radiation on elastomeric and plastic components and materials from 1961 to the present.

The mechanism of radiation damage and the effects of radiation in various environments are briefly discussed. Data summarizing the radiation-effects information on specific components and on the various types of elastomers and plastics are presented in detail. Areas in which additional work is needed are indicated. Radiation polymerization or vulcanization are not covered in this report.

The report is intended to be sufficiently inclusive to make it valuable as a reference guide relative to radiation effects under varying conditions of temperature and vacuum on elastomeric and plastic components and materials.

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